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FIRST RESEARCH CONFERENCE ON

UTILIZATION OF SAFFLOWER

Held May 25-26, 1967
Albany, California

AGRICULTURAL RESEARCH SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

THE FIRST SAFFLOWER UTILIZATION RESEARCH CONFERENCE was held May 25-26, 1967, in Albany, Calif. Sponsors were the West Coast Oilseeds Development Committee and the Western Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

The purpose was assembly and coordination of information from agronomic research, from utilization investigations--which include composition and processing--and also from economic studies. Conferences like this one bring fields of research and branches of industry together. The result is an organized body of facts that evaluate achievements and guide future efforts.

Safflower is a comparatively new crop. Realization of its potentials and avoidance of misdirection are important at the present stage of its development.

The sponsors are grateful to all contributors and participants, who include State and Federal research workers and industrial leaders.

This report was prepared in the Western Regional Research Laboratory, Albany, Calif. 94710, headquarters of the Western Utilization Research and Development Division, Agricultural Research Service, USDA. Occasional mention of commercial products does not imply recommendation by the U. S. Department of Agriculture to the exclusion of other comparable products. Numbers in parentheses refer to references at the end of each paper. The artwork, references, and tables are reproduced essentially as they were supplied by the writer of each paper. Copies of this report are available on request.

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ROLE OF OILSEEDS IN WORLD FOOD SUPPLY

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The world food supply, or more accurately, deficiencies in the world food supply, is a subject frequently before us in the news. Before I come to the subject of oilseeds, I would like to sketch some aspects of the world food situation. It must be recognized at the outset that inadequacies in diets are personal and individual. A shortage of food is experienced by an individual. When we look at the world today, however, we see vast areas where very large numbers of people are perilously underfed and even larger numbers are on inadequate diets. We can then speak of poorly fed countries.

To become specific, we might first examine the food protein situation in the world today. Table 1 shows the world supply of

Table 1.--Food protein availability in the world, estimated for 1970

Protein source	Per capita per day	Total protein
	Grams	1,000 metric tons
Animal	20.5	27,000
Pulse	8.4	11,100
Other plant	38.5	50,800
Total	67.4	88,900

protein, projected for 1970.[1] When we examine the protein supplies in light of the recommended minimum for an adult of 60 grams of protein, including 10 of animal protein, per day, it would seem that, at least for protein, there is no immediate shortage. However, incomplete statistics are sometimes misleading, as in the case of the statistician who drowned when wading across a river with an average depth of 3 feet.

[1] Q. West. The World Food Budget, 1970. U.S. Dept. Agr. Foreign Agr. Econ. Rpt. 19, 105 pp., 1964.

Table 2.--Protein availability--by areas of diet adequacy, estimated for 1970

Protein source	Diet-adequate countries 1.2 billion population		Diet-deficient countries 2.4 billion population	
	Per capita per day	Total 1,000 metric tons	Per capita per day	Total 1,000 metric tons
	Grams		Grams	
Animal	43.1	19,000	8.6	7,400
Pulse	5.3	2,400	10.0	8,700
Other	38.0	17,200	38.8	33,600
Total	86.4	38,600	57.4	49,700

In table 2 we see a comparison of protein supplies for two groups of countries, the well fed and the poorly fed. Here we see that for the well fed third of humanity, protein supplies are more than ample, but for the poorly fed two-thirds, the averages of total and animal protein are below the recommended minimum for adults. If we break this down a little more, as in table 3, we can see that for particular countries, the shortage of protein is

Table 3.--Average diets in various countries, estimated for 1970

Diet	Per capita per day			
	USA	Brazil	India	West Coastal Africa
Protein:				
Total g.	96	67	59	54
Animal g.	65	22	8	6
Calories	3,180	2,890	2,220	2,530

even more marked. Moreover, when we examine the food supplies for India and West Coastal Africa, we find also a shortage of calories. We see here the present situation. What if we look ahead?

It is common knowledge that we are experiencing a rapid, worldwide increase in population. Estimates of population projections vary widely, but all agree that, barring catastrophe, the world population will be much larger in the year 2000 than it is now. Lester Brown puts the world population at 6.3 billion persons.[2] We can see what this will mean in terms of food supplies. Table 4 shows an estimate of the world food protein situation in the light of the projected population increase. To provide adequate diets, we must increase our supply of protein by 50 million tons. Our requirement for vegetable protein will be almost twice as great as the estimated supplies for 1970. The urgency of the problem is emphasized when we look particularly at the less developed and

[2]Lester Brown. Man, Land, and Food. U.S. Dept. Agr. Foreign Agr. Econ. Rpt. 11, 153 pp., 1963.

Table 4.--Future world food protein requirements
(Estimated population: 1970, 3.6 billion; 2000, 6.3 billion.)

Food protein	Estimated supply 1970	Needed as per standard[a] 1970	2000
	1,000 metric tons	1,000 metric tons	1,000 metric tons
Animal	27,000	13,000	23,000
Other	61,900	66,000	115,000
Total	88,900	79,000	138,000

[a]Standard - from World Food Budget: 60 g. of protein per person per day; 10 g. of animal protein per person per day.

presently poorly fed areas of the world. Table 5 shows the projected needs for Asia. The projected needs will exceed present supplies by 40 million tons of protein by the year 2000. Both animal and other protein supplies will have to be approximately double the present supplies.

Table 5.--Food protein requirements in Asia

Food protein	Estimated supply 1970	Needed as per standard 1970	2000
	1,000 metric tons	1,000 metric tons	1,000 metric tons
Animal	6,300	7,600	14,100
Other	37,000	37,700	70,700
Total	43,300	45,300	84,800

Table 6 shows the situation in Africa where a large increase in the vegetable protein supplies will be needed. In Latin America (table 7), the requirements for vegetable protein will be more than twice the presently available amounts. Thus the pattern of protein needs differs for each area, with a need in Asia for large increases

Table 6.--Food protein requirements in Africa

Food protein	Available 1970	Needed as per standard 1970	2000
	1,000 metric tons	1,000 metric tons	1,000 metric tons
Animal	1,610	1,180	1,890
Other	6,030	5,890	9,430
Total	7,640	7,070	11,320

in both animal and vegetable protein, in Africa a greater need for vegetable-protein increases than for animal protein, while in Latin America, there is a need for increases in vegetable protein only, on the average. Several countries are deficient in animal protein.

Table 7.--Food protein requirements in Latin America

Food protein	Available 1970	Needed as per standard 1970	Needed as per standard 2000
	1,000 metric tons	1,000 metric tons	1,000 metric tons
Animal	2,470	1,020	2,160
Other	4,450	5,110	10,810
Total	6,920	6,130	12,970

We have seen that a worldwide sufficiency of protein does not mean that all areas have enough. We find also that within regions and countries there is a nonuniform distribution of protein supplies between segments of the population and even between members of a family. The name "kwashiorkor" has been given to a deficiency disease observed in children, where the supply of protein is low, although calorie intake is adequate. The word literally means "the child that has been displaced" and symbolizes the infant taken from the mother's breast when its younger sibling pre-empts its position there. Kwashiorkor occurs in tropical areas, even where the supply of protein would appear to be sufficient, or nearly so. One aspect of the problem is indicated in table 8.

Table 8.--Calorie and protein allowances for various age groups

Subject	Calories per day	Reference protein, grams per day
Infant ----------(0 to 1 years)	--	--
Toddler ----------(1 to 2 years)	1,230	24
Child ----------(4 to 9 years)	1,970	29
Adolescent----------	3,050	61
Adult ----------	2,960	34
Lactating mother ----------	3,200	76

The data are taken from the work of B. S. Platt in the Department of Human Nutrition, London School of Medicine. Platt and his associates calculated the safe percentage of protein calories in a diet by combining the recommended calorie allowances for human subjects per kilogram per day with the protein allowances on the same basis. Taking figures submitted by committees of the Food and Agriculture Organization, they arrived at results shown in table 8. These data emphasize the importance of protein nutrition to the lactating mother. On this basis, her minimum requirement is even higher than that of the infant. Notice the importance given to protein in the diet for adolescents and the comparatively low requirement for adults.

Platt's protein requirements are in terms of "reference protein," and are not on the same basis as the protein requirements

in previous tables. When adjustments are made for Net Protein Utilization and protein-calorie balance, the food protein requirements would be much larger--approximately double the figures in the table. I wish to emphasize the large variation in protein requirements for various age groups. The protein allowance for children under the age of three indicates that their diet should be high in protein, because they simply cannot eat enough of a low-protein diet to meet their needs. A critical shortage of protein is rarely observed in an adult, except where it is accompanied by a shortage of calories.

This brief review has indicated the magnitude of the problem. What about solutions? In the first place, the problem is largely one of population, but it is also one of purchasing power, distribution facilities, social conditions, religious beliefs, regional food habits, poorly developed agricultural technology, lack of fertilizer, and inadequate storage facilities, which allow very large losses due to spoilage, infestation, and rodents. What can we do, and where do we begin? I believe the answer is that all of these factors are important, and that none can be neglected. A discussion of efforts now being put forth in all of these areas is not appropriate for us today. I will concern myself with the potential role of oilseeds in helping to alleviate the problem.

The Food for Peace program clearly obligates the United States Government to mount a substantial and immediate effort to assist the developing countries in the providing of foodstuffs for the undernourished in their population, with emphasis on the more vulnerable segments such as weanlings, pregnant women, and mothers. This requires assisting a country in providing food in general but in particular providing nutritionally balanced foods. A major imbalance is lack of protein, which is generally low in the diet, but frequently it is not only insufficient in quantity but also in quality. Vitamin and mineral deficiencies also are important in many regions and should not be overlooked. Emphasis is on temporary assistance to allow the countries to develop their own supplies of food.

The most attractive sources of basic material for new protein-rich foods have been the industrial oilseed residues remaining after expressing or extracting the oils. Vast quantities of the residues from various seeds are available in many countries where the most serious protein malnutrition problems exist. Traditionally these residues have been used mainly for animal feed, either locally or after export, or for fertilizer, but with modification of processing and handling techniques they can be made valuable adjuncts to human diets. At least one of the major oilseeds (cottonseed, peanuts and soybeans) as well as safflower now grows or can be grown in all protein-deficit areas.

The fact that over 99 percent of the high-protein meals produced in commercial processing of these oilseeds is used for fertilizer or animal feeds shows that there is a serious lack of available technology for their manufacture into the more valuable food uses in developing countries. Coupled with this is a lack of appreciation of the potential contribution of oilseed proteins as food.

Part of research of the past 25 years in the utilization research laboratories of the Department of Agriculture has been directed to basic and applied studies of the chemistry and technology of oilseed proteins. The nutritional value of the protein in animal feeds, when correctly processed, was demonstrated. Studies of the composition of the proteins and their properties in special food uses have been carried out.

Our Divisions in Human Nutrition and Consumer Use Research have contributed their competencies in food composition, food quality and acceptance, and most importantly, have determined nutritional requirements for growth and maintenance of children and adults. The basic methods of upgrading the three major oilseed meals (peanut, cottonseed, and soybean) to human food differ in detail, but they all have the common problem of sanitation--maintenance of low bacterial counts and freedom from toxic organisms or toxins produced by microorganisms.

Cottonseed contains gossypol, cyclopropenoid fatty acids (little is known of effects of these acids on humans), and possibly mold toxins (mycotoxins). Peanuts do not naturally contain antimetabolites, but their growth, harvesting, and storage conditions in tropical countries favor the development of mold toxins.

Soybeans. Soybeans contain a variety of antimetabolites, which are destroyed by normal heating processes. There does not seem to be an important mycotoxin problem of soybeans in the United States. There have been few studies of this problem in truly humid regions. Soybeans also have a bitter or beany flavor that must be removed or destroyed if they are to be generally acceptable as food.

I would like to describe some of the progress which our Utilization Research Laboratories have made in the last few years.

Development of a village industry process, which could produce a soy flour for use as a beverage, in bread, and in other cooked foods, has been completed. The process involves soaking, brief cooking, air drying, hull removal, and grinding in a hand-powered mill. The equipment used costs less than $125. No electrical or steam power is required. It is estimated that five men working an 8-hour day could produce 300 pounds daily. This

quantity can supply half the daily requirements of plant protein for 1,600 adults.

The full-fat soybean flour produced in this way contains over 40 percent protein and 20 percent fat. It is ready for use in soy beverages, and as a component of breads, soups, curries, and other cooked dishes. The flavor of soy beverage made by this process compares favorably with that from industrial manufacture. It can be improved by additives (sodium bicarbonate or sodium phosphate) in the soaking water. Flavors can be added to produce chocolate, fruit, and spicy tastes with desired sweetness.

The oxidative stability of the full-fat flour appears to be good. Tests under way show no rancidity or off-flavor at 10 months' storage at room temperature.

Nutritional value, as indicated by chemical indices (available lysine, urease activity, trypsin inhibition, and nitrogen solubility index) should be high. Animal feeding tests are in progress and infant feeding tests are planned.

Efficient high-capacity equipment that very rapidly cooks cereal products and extrudes them through a die in various shapes is widely used in the feed and food industry. Adaptation of this equipment to process soybeans to a full-fat food product was reported in work done jointly by our Northern Utilization Research Laboratory, UNICEF, and the industry. Development of smaller scale equipment of this type has also been undertaken by industry.

It is highly desirable that process conditions be established for optimum nutritive value, flavor, functionality, and stability of the product. The high-capacity machine is obviously not a satisfactory research tool for investigating the parameters of temperature, moisture content, rate of passage, oil content, and pretreatment of beans that affect the above-listed properties. For this reason, a modified plastic extruder was secured at NRRL that can be regulated through the range of variables under study.

The major result to date has been the finding that an initial dry heating step effectively inactivates the lipoxidase normally present in soybeans. When the soybeans are subsequently moistened before cooking-extrusion, no enzyme action takes place.

Smooth and effective extrusion has been difficult to achieve at the high temperatures and rapid throughput desired. An improved extrusion screw is being designed on the basis of experiments on compression, oil release, moisture content of beans, etc. These data will establish optimum conditions for cooking-extrusion.

Cottonseed. A novel process for manufacture of high quality cottonseed meal for animal-feed use developed at SRRL was patented in 1960-62. It utilizes acetone, hexane, and water (AHW), either as the azeotropic mixture or in the general range of 60 percent hexane, 40 percent acetone, and 1 to 4 percent water. Engineering development of this process to produce a food grade cottonseed flour was initiated because the product was shown to have excellent nutritive value for animals.

This process reduces gossypol to a low level and removes 60 to 85 percent of any aflatoxin present. The highly reactive gossypol appears in the oil and must be removed by a more complicated two-step refining process called miscella refining.

In conversion of this feed-grade process to food-product manufacture, it was found that the flour had a bitter flavor. Research established that this flavor was caused by condensation products of acetone, diacetone alcohol, and mesityl oxide, initially present in commercial acetone and produced in high-temperature phases of the process. Means of minimizing this effect have been worked out and will be reported soon.

In experimental animals the AHW processed cottonseed flour has produced excellent growth. Child-feeding tests, conducted by George Graham, through the cooperation of UNICEF, have given excellent results. The AHW process is now ready for advanced engineering design and cost analysis. This is a complex process requiring sophisticated engineering equipment and capability. It is in no sense a village industry.

An alternative procedure has been explored that is promising. It consists of a low-temperature hexane extraction of oil followed by extraction with aqueous acetone (90:10). This process has the advantage of using conventional oil extraction and refining equipment, and excellent removal of gossypol and aflatoxin. It has the disadvantage of requiring two extraction and solvent systems, with consequent greater capital investment and operating costs.

Peanuts. Other work at SRRL has been directed to making high-protein foods from peanuts. The possibility of mycotoxins in peanuts is ever-present, especially in tropical conditions. Peanuts are necessarily harvested at a high moisture content, and if post-harvest conditions favor the development of fungi, the possibility of contamination with the fungal toxins must be considered. Therefore, processes that minimize toxins in peanut flours are a major aim of this research.

The two-stage process--hexane followed by aqueous acetone--is readily applied to peanuts. This process gives an excellent grade of oil and a high-quality meal or flour. If the need for

local or export markets of the oil is great, this two-stage process produces a marketable oil and a valuable protein food.

If the high caloric value of the oil and its content of polyunsaturated fatty acid are considered paramount in the diet, use of the aqueous-acetone extraction process alone to remove aflatoxin is recommended. This process can readily be used with a low-temperature prepressing to remove part of the oil for market. The peanut flour so produced can be incorporated in many foods.

Formulation and acceptability. The nutritional value of the oilseed proteins, when properly prepared, has been established. The next problem is--can you put nutritionally useful amounts of them into foods that people want to eat? When we consider the many cultures and varying food habits and likes, this question becomes a formidable one.

Our Human Nutrition Research Division has attacked this problem imaginatively. Nutritionists and home economists who have returned from many foreign assignments were consulted. Foods of Latin America, Africa, and Asia were then prepared and evaluated for performance, appearance, texture, and flavor. Palatability evaluation was the determining factor in selecting the final formulas for the food products. Adult panel members found it difficult to evaluate the products designed for babies, such as beverages, porridges, and pureed foods, all of which were very bland in flavor. Perhaps the flavor of most baby foods reflects adult tastes more than that of babies.

Palatability ratings of the products are encouraging. Soy flour produced by the simplified process with bicarbonate or phosphate in the cooking water has improved dispersibility in water and is readily made up to an infant's beverage.

Peanut flours also can be readily dispersed to a beverage. Cottonseed flour has a darker color and a characteristic flavor and aroma. Recent samples, produced by the AHW process, were satisfactorily made into bread and drop biscuits which contained cottonseed protein equivalent to that from the flour. The panel evaluation of the bread was good to very good.

A cooperative agreement has been set up with Howard University in Washington, D.C., for research on preparation, palatability evaluation, and acceptance of food products containing the protein flours. There are over 2,500 students from 29 African and Asian countries at Howard University now. Here foreign students from developing countries make the foods of their country and evaluate them. This study has an additional value in that on return to their own country, these students will know of these products and their possibilities.

The Institute of Nutrition of Central America and Panama, more familiarly known as INCAP, has developed a number of vegetable protein foods, specifically designed to provide a highly nutritive food at low cost. Since 1961 these foods, known as Incaparina, have been in commercial production in Central America and are rapidly gaining acceptance. Production has gone from 200,000 pounds in 1962 to 4,000,000 pounds in 1965 and has accounted for a consumption of about 1,500,000 pounds of cottonseed protein through 1965.

It should be emphasized again that the use of oilseed protein in foods is dependent on the application of recent technological advances. The residual meal from oilseeds has traditionally been considered inedible, and direct utilization for food can follow only after processes are developed for removal of toxic components and off-flavors. We now come to the question, "How does safflower fit into the picture of oilseeds and food?"

At the present, safflower must be considered as a minor oilseed when compared with other oilseeds, either on a global basis or in the United States. It is, however, "new" in that only recently has effort been expended to develop varieties and improve the production and utilization potential. We will hear a great deal on this subject from other speakers, but I would like to point out some aspects of safflower's potential throughout the world. Safflower is an ancient crop in Africa and Southern Asia, and varietal developments in the last few years have shown that the production potential is very large. Safflower can be grown in many areas of the less-developed countries on land which is not well utilized at the present, since it grows under semiarid conditions but also responds well to irrigation. Thus, one of the first requirements can be met--it is a crop which could be locally available. Safflower plantings in the last 2 years have been greatly increased in Mexico, Spain, and Australia, and we hear of plantings in Venezuela. However, considerable research will be necessary to develop practical processes for removal of fiber and bitter flavor from safflower meal. Products obtained in research to be conducted in the Western Utilization Research Division, will be evaluated for flavor, nutritive value, and utility in a variety of food products designed for the United States and specific areas of the rest of the world.

When we examine the value of oil and meal products from soybeans and cottonseed, we see that over the years there has been a large increase in the relative value of the meal. This largely reflects development of animal agriculture and the demand for meal but also is a reflection of the technological advances in processing which have allowed these meals to move into the feed market and now into the food market. Safflower meal development is in an embryonic stage, but there is no reason to expect that its story will be different.

ECONOMICS OF CALIFORNIA SAFFLOWER PRODUCTION AND UTILIZATION

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Fully recognizing that there is great economic competition among crops for profitable land use in California, we believe after careful analysis that safflower will continue to be even more successful in the areas where it is now securely established. We expect safflower to occupy its proportionate share of the additional 3 million acres expected to be brought under irrigation mostly in the Great Valley by the year 2000.

In reaching this opinion, we have implicit confidence that the workers (public and private) in the sciences related to primary production of safflower will (1) provide improved, higher-producing varieties yielding products of essential value to food and industrial manufacturers and (2) develop better and more economical cultural practices. California safflower growers will become even more expert in growing the crop. As these events transpire, we believe industry will continue its long-established pattern of progress, developing new and expanding uses for the improved varieties which will have been especially tailored and produced to meet its needs.

Present safflower use. Thanks to information supplied in day-to-day contacts with the industry and available USDA reports,[1] we size up the safflower utilization position about as follows. Of the estimated 1966 U.S. safflower crop of about 370,000 tons, about 50 percent hopefully will be exported. Historically Japan has been one of our best export markets. Because of their nearness to the Asiatic market, California-grown oil crops should in the foreseeable future have an economic advantage as compared with those grown east of the Rocky Mountains.

About 12.5 percent of the 1966 crop will be used by industrial coatings such as paint. The remaining 37.5 percent will be used for food purposes. The development of "soft" margarine has produced a salutary effect upon the use of safflower oil for food purposes.

U.S. safflower's competition. The specialized product which has caught the fancy of the shopping housewife in the form of "soft" margarine has sharpened competition from other types of vegetable oil. The safflower seed producer should never forget that he must remain competitive with other producers of oilseeds. The modern user in industry or in food processing can economically and easily substitute one vegetable oil for another, with cost as the deciding factor.

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[1]Fats and Oils Situation (1967 Outlook Issue), FOS 235. U.S. Economics Research Service. November 1966.

At present, the foreign production of safflower has not been a real competitive factor. Mexico's 1966 crop has been estimated at 230,000 tons and for the first time that country offered safflower in international trade. This is only about 100,000 tons less than the California crop. Although Australia, Argentina, Spain, India, and several other countries have commercial production, none to date has exported any significant quantity.

Safflower's real U.S. competitor for domestic utilization is soybeans. This crop was grown on 36.9 million U.S. acres in 1966 and is probably being grown on 40 million U.S. acres or more in 1967. Fortunately the U.S. total marketable supply of soybeans for the 1966-67 year is close to the domestic and expected export requirements. There was a carryover of only 36 million bushels into the marketing year. With 1966 production set at 927 million bushels, and both domestic and export demands expected to increase in 1967, no unmanageable soybean supplies are expected to build up within a year or so.

Some people are now estimating a carryover of about 100 million bushels of soybeans into the 1967-68 marketing year. While the carryover is larger than into this year, it still is only about equal to 1 month's normal disappearance. However, since 25 to 30 percent of the crop usually is exported, what happens to the soybean export market becomes important to safflower producers and users of safflower oil and meal. A sharp drop in soybean exports could mean serious trouble for most oilseed producers.

Supplies of cottonseed oil and meal are directly related to the production of lint cotton. Its supply is determined primarily by economic and governmental factors affecting cotton. U.S. cotton acreage has dropped sharply from the 26.9 million in 1951 to 9.8 million in 1966, a decline of 64 percent. Cottonseed output, therefore, does not adjust to changing demands and price levels for oilseeds, edible oils, and oilmeals. To illustrate, because of the lint cotton situation there was a reduction of 28 percent in the 1966 acreage as compared to 1965. Thus:

1965 U.S. production of cottonseed = 6.1 million tons,
1966 U.S. production of cottonseed = 4.2 million tons.

As a consequence:

1965 U.S. production of cottonseed oil = 2.3 billion lb.,
1966 U.S. production of cottonseed oil = 1.6 billion lb.

With the lint cotton outlook somewhat clouded, there is little likelihood of a sharp increase in cotton acreage in the immediate future. Thus, safflower oil and meal demand will be primarily geared to the soybean situation.

Because of the almost overwhelming nature of the giant U.S. soybean industry, it is natural that there should be genuine interest in a soybean industry in California. The Department of Agronomy of University of California, the USDA, and members of the oilseeds industry have cooperative research under way in California on development of soybeans. Although results have been encouraging, it is not likely in the next few years that safflower and soybeans will be competitors for California land and production capital use. Incidentally, with current possible yields, California would need to grow 400,000 acres of soybeans to meet its own needs for soybean oil and meal which are now imported from the Midwest.

The California livestock industry to 1975. My friends in the oilseeds industry long have told me their margin of profit in producing vegetable oil is directly related to the oilseed meal production and marketing picture. In this paper we shall accordingly concentrate on the economic factors related to the utilization of the byproducts resulting from safflower oil production. What is going to happen over the long haul to our multimillion dollar poultry and livestock industry is of prime importance to all oilcrops grown in California, and to safflower in particular.

G. W. Dean and C. O. McCorkle, Jr., of the University of California Giannini Foundation, after a lengthy study, have forecast California livestock trends through 1975. Here they are:

1. Dairy cattle.--Numbers should rise by 40 percent to 1,209,000. This assumes a 21 percent increase in production per cow in order to meet needs of the expected California population in 1975 of 23.6 million people.

2. Beef cattle.--It will take 5.5 million head to meet California's beef meat needs annually. California cattle feeders are expected to supply 48 percent of this, or 2.64 million head. This is an increase of 39 percent over 1963.

3. Sheep and lambs.--Over the past decade California averaged about 1,200,000 lambs raised with net in-shipments of stocker and feeders averaging about 330,000 per year. Sheep and lamb numbers in California are expected to decline about 10 percent.

4. Hogs.--Production in California has declined since World War II. The State has produced only about one-fifth of the swine butchered here annually. Hog numbers are expected to continue to decline, reaching a low of about 300,000 in 1975. Thirty percent less feed will thus be needed for swine than at present.

5. Egg production.--By 1975 the number of layers in California and the corresponding total feed-grain requirements each are projected to increase by about 60 percent of the average of 1954-57. California egg producers have found a real economic advantage in producing shell eggs for the home market and likely will expand this advantage.

Table 1.--Protein supplements used by California feeding industries in 1963

Industry	Cottonseed meal	Meat meal and meat scraps	Other protein supplements[a]	Soybean meal	Fish meal or fish products	Total
	Tons	Tons	Tons	Tons	Tons	Tons
Livestock						
Beef	130,197	--	47,368	--	--	177,565
Dairy (milk)	64,157	--	91,103	--	--	155,260
Dairy (replacements)	12,647	--	12,286	--	--	24,933
Swine	3,959	3,959	--	7,919	1,584	17,421
Sheep	678	--	77	--	--	755
Total	211,638	3,959	150,834	7,919	1,584	375,934
Poultry						
Chicken egg	56,687	122,822	15,116	56,687	69,914	321,226
Broiler-fryer (meat)	13,841	22,146	8,304	20,070	13,841	78,202
Broiler-fryer (eggs)	1,139	2,735	1,139	2,735	--	7,748
Turkey (meat)	29,038	58,075	5,807	23,230	23,230	139,380
Turkey (eggs)	1,788	5,362	715	5,363	3,575	16,803
Total	102,493	211,140	31,081	108,085	110,560	563,359
Miscellaneous						
Horses	--	--	1,630	--	--	1,630
Pet food (dry)	--	--	2,800	22,400	11,200	36,400
Pet food (canned)	--	--	--	12,432	--	12,432
Rabbits	--	--	3,557	--	--	3,557
Human food	--	--	--	--	--	--
Total	--	--	7,987	34,832	11,200	54,019
Total utilization	314,131	215,099	189,902	150,836	123,344	993,312

[a]Includes coconut meal, linseed meal, corn gluten meal, dried milk products, safflower meal, etc.

6. Turkeys.--Numbers of turkeys are expected to remain about the same, with a greater percentage of the crop being consumed within the State. Export is expected to decline to about half that at present.

7. Broilers and fryers.--Numberwise this industry has been relatively static since 1961, varying annually in the 150- to 160-million pound range. Dean and McCorkle predict that California broiler production will remain pretty nearly at its present level of about 157.3 million pounds, because the competition of out-of-State imports is likely to continue quite stiff.

California protein supplement usage. Accurate annual data on the usage of protein meal by the California poultry and livestock industry are difficult to come by. A special study in 1963 by the California State Department of Agriculture[2] provides about the best recent generalization on utilization of feedstuffs. Industry and University of California nutritionists cooperated with the Department in the study.

This special survey showed that in 1963 a total of 993,312 tons of protein supplements were used within the State. This is the equivalent of a trainload of 69 boxcars (40 tons each) every day of the year. In that same year California only produced about 307,305 tons of cottonseed meal or about one-third of the amount of protein supplement used. Table 1 from that report shows the amounts and various sources of protein used in 1963.

Safflower meal vs. other protein sources for beef and dairy cattle. University of California's Extension Animal Nutritionist Donald Bath tells us that ruminant animals, such as beef or dairy cattle and sheep, can use most sources of protein or nonprotein organic nitrogen to provide their essential amino acid needs. The microorganisms in their rumens use the nitrogen for their own purposes. In turn the organisms that contain all of the essential amino acids pass into the other stomachs of the animal, where they are digested, releasing the required amino acids for the animal's use. Thus beef and dairy cattle feeders are primarily interested in the cheapest available source of protein, and total net energy is their primary concern. Safflower meal has about five-sevenths of the net energy of cottonseed meal and about five-eighths that of soybeans.

For poultry. Ralph Ernst, University of California Extension Poultry Specialist, helped us summarize the comparative merits of protein supplement sources for poultry. Soybean meal is one of the few plant protein sources which contain excess lysine and can

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[2]Utilization of Feedstuffs by California Feeding Industries, Calendar Year 1963, State of California Dept. of Agriculture, Sacramento, April 1965.

serve as supplements for lysine-low cereal proteins. While raw soybeans have poor nutritional quality, properly processed soybean meal is a very valuable feedstuff, deficient only slightly in methionine for poultry use.

Cottonseed meal, on the other hand, contains a considerably lower level of lysine, which is usually adequate when cottonseed protein is used alone but cannot make up the deficiency of the cereal proteins. Cottonseed contains gossypol, which is detrimental to growth and egg quality in poultry, but its effect can be minimized by proper processing and use of biologically tested samples.

Safflower meal has an even lower level of lysine than cottonseed meal but does not contain any detrimental components which limit its use in poultry rations. The amino acid deficiencies and excesses can be balanced in the complete poultry ration by the use of combinations of ingredients. Certainly all three of these meals should be kept in mind while formulating the poultry ration for economical production.

Safflower in California crop rotations. We believe that use of safflower will continue to expand in the Sacramento and San Joaquin Valleys. It fits well into the planting and harvesting schedules of other popular crops. From time to time impeding problems arise, but vigorous research usually provides an answer.

Historically on certain soil types safflower has done poorly when planted immediately following rice. Current research by U. C. Farm Advisor Robert Sailsbery and others is showing that heavy application of phosphorus fertilizer may be the answer.

San Joaquin Valley cotton growers have become progressively concerned about the reduced yields resulting from Verticillium wilt damage to cotton. In 1966 it was shown that the especially virulent strain would commonly infect cotton and safflower.

Research by University of California and the USDA is already providing leads to a solution to the problem. A new fungicide applied as a seed treatment looks promising for Verticillium control in cotton. Deep plowing to cover crop debris looks helpful. And P. F. Knowles, as well as industry plant breeders, is screening a collection of lines to develop a Verticillium-resistant variety.

San Joaquin Valley growers, in high-water-cost areas, have found that they must use more water to keep an ensuing crop of cotton productive than was the case where winter-grown barley or shallow-rooted vegetable crops preceded cotton. Counter-balancing this problem is the beneficial effect safflower has been observed to have on soil structure and infiltration rate.

California safflower growers still are plagued by lack of varieties that have sufficient resistance to Phytophthora and rust. We feel relatively certain that when varieties with resistance become available, there can and will be a significant upswing in California acreage devoted to the crop.

Cost of growing safflower in California. For safflower to survive in California, it must make a profit for the producer and the processor and also provide the consumer with a needed product. Using current economic studies conducted by University farm advisers in safflower-growing districts, we have compared the financial advantages of safflower vs. barley. These studies show plus returns for both crops when only cash or cash and depreciation costs are considered. In all cases except barley on Sacramento Valley rice farms, negative returns result when interest on the investment in equipment and land is included as a cost. It is quite typical for barley to be grown as a double crop on Sacramento rice farms with only one-half the interest cost of land being shared by this crop. This results in the small plus return of $5.65 per acre. Had full interest been charged to the barley crop a minus return would have occurred. To fully measure the value of growing either safflower or barley, one must also consider the effect of the specific crop on the overall cropping pattern.

In the short space of 20 years, safflower has firmly established itself in our economy. All of those involved can rightfully be proud of their contributions and achievements to date. True, both economic and scientific problems concern all of us interested in the future of safflower. However, history records that all developing crops have faced growing pains. Even the giant of the oilseeds world, soybeans, did not coast to its present position of dominance.

The challenge now, just as it was in the beginning, to you who pioneered the crop is to make safflower a commodity that will economically provide consumers, wherever they may be, with products that are uniquely necessary to their well-being. We believe the vigorous application of science and technology on the production, processing, and marketing fronts will do just that. Safflower has a bright future--especially here in the West.

PLANT SCIENCE RELATED TO UTILIZATION

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A farm crop, like anything else, must be useful and must be able to compete successfully if it is to survive.

First of all, a crop must be profitable to the farmer, and it must be attractive to him when he considers his other management options. These options may include production of different crops, production of some other agricultural commodity, a change from farming to some other kind of activity, or simply investing his money. The nearly complete disappearance of safflower from western Nebraska and adjacent areas where it was once thought to have a bright future illustrates the importance of crop attractiveness to the farmer.

But no matter how attractive to the farmer, a commodity must find its place in the market; there must be an end use. This means that composition and quality are important. We can cite examples of crops which have troubles due to lack of farmer acceptance and others whose troubles are related to market acceptance.

Crambe, for example, apparently could find a small but significant market in the steel industry and other uses. Yield and price factors are such that progress in obtaining farmer acceptance, however, has been slow. Flax perhaps illustrates problems at both the farmer and the market level. The use of synthetic materials for paint has reduced the demand for linseed oil. This in turn affected the price so that flax production has almost disappeared in the Imperial Valley and alternate crops are being sought in other areas.

Processors and workers in utilization research are primarily interested in composition and quality. We in production research are also interested in quality, and I think we can make a significant contribution. A good example is Dr. Knowles' work on the high-oleic-acid safflower lines. Another example is the work at Arizona where a significant increase in oil has been obtained in lines that have a thin hull or a striped character.

The biology of these examples is different, however. In the case of the UC-1 line there has been a genetic change in fatty acid synthesis. By contrast, the increased oil due to the thin hull and striped character results from a lower hull percentage. There is little or no evidence that the oil percentage or quality in the meats of thin-hull or striped lines differs significantly from other genetic types. However, since the change in composition is

achieved by reducing the amount of hull, we have a chance to increase not only the oil but also protein percentage. Reduction in fiber and other undesirable components of the hull further enhances the value of the meal.

There are also achievements in other crops which could be cited as examples of improvement in product quality through production research. Perhaps the best known at the moment is the high-lysine line of corn. Because lysine is the major limiting amino acid in corn, a twofold or threefold increase in lysine has the effect of increasing the usefulness of the protein in about the proportion of the increase in lysine. Programs to incorporate this character into good agronomic types are now in the third or later backcross generations. Some yield tests in 1966 indicated yields within 10 to 15 percent of present commercial hybrids.

Another example is glandless cotton. Elimination of the lysigenous glands is considered desirable by the cotton oil industry, and is technically possible. Incentive is lacking, however, because the oil contributes only a minor part of the total value of the cotton crop.

After noting these results of production research, which are valuable from a utilization point of view, I would like to place the subject in what I consider to be its proper context.

The best opportunity to increase the supply of oil, protein, and other economic materials and to lower the price is to increase yield. Why is this so? There are both economic and biological reasons. Trading rules are such that the farmer usually gets paid by the pound, bushel, or ton. Grading standards relate to moisture, appearance, foreign materials, etc. They take little note of the composition of a given farmer's product. They usually do not reward him for producing a high-oil material, nor do they penalize him for low oil or protein. Wheat I believe is the only major crop in which composition is reflected in the grading standards and in pricing. There is talk of including oil and protein levels or both in the pricing system for other crops. There are substantial problems, such as the difficulty of making a quick analysis and the inconvenience of keeping a given farmer's material separate before and after it has been analyzed. It might be easier to establish such a system for a commodity like safflower where trading is in an essentially closed market, varietal control and identity are relatively easy, and seed does not get mixed in country or terminal elevators.

The biological reasons why increased yield is important are that oil, fatty acids, protein, and other constituents, when expressed in percentages, are closed-end parameters. The theoretical sum is 100, and the percentage content of one component can increase only

at the expense of another. This is illustrated in the thin-hull safflowers. The amount of hull decreases; therefore percentages of other components increase. On the other hand, yield is an open-ended concept. If there is a theoretical maximum yield, it is so far above present yields as to be indefinable. Consider, for example, the yield history of corn. Average yields have doubled since 1949, and there are few who would say that yields are near the ceiling. Yields of other crops such as cotton, tomatoes, and peanuts are also about double what they were 20 years ago. Thus, with a constant composition, the amount of oil or protein or whatever the significant constituent may be, has doubled because of increased yields.

There is much interest in protein now as we realize more clearly that all human welfare really depends on adequate supplies of protein from plants. It is relevant to note that the protein percentage of the corn hybrids which are contributing so much to our total production is possibly lower and certainly no higher than that of their open-pollinated forebears. Yet the total protein production of corn hybrids is vastly greater than would have been possible with the seed stocks and production practices of a generation ago.

When we talk about yields and their importance to a commodity, other aspects of our research also fall into place. Disease problems in safflower can be very severe. I think this is reflected in the fact that of a small total number of research people, an unusually large proportion have been pathologists. This work on diseases is paying off, too. We now have varieties with a high degree of resistance to rust resulting from the research program of D. E. Zimmer at Logan. There appears to be a useful type of resistance to Phytophthora rot in the Biggs selection, and when this is incorporated into good agronomic material, it will contribute to increasing and protecting good yields. This work being done by C. A. Thomas is well advanced. A considerable effort is under way at Davis by L. Johnson of the University of California and J. M. Klisiewicz of the Crops Research Division, who are working together to develop a fuller understanding of Phytophthora rot. There is progress as well toward the control of other diseases such as Verticillium wilt and fusarium.

The rapid increase in variety development activity by breeders associated with commercial firms will have an impact on the research program of the Crops Research Division and of the experiment stations with which we associate so closely. There is less need for a publicly supported variety development program if industry is capable of fulfilling this role. This has been the history of variety development in corn since the advent of hybrids and more recently in sorghum and alfalfa. Present indications are that a similar trend will occur in safflower.

We therefore expect that our agronomic research on safflower in the future will be more concerned with principles of inheritance and the production of genetic materials which can be released for use by private breeders than with developing varieties. Our work on diseases will probably continue at about the present level.

Such a change in research obligations can be a cause for both concern and satisfaction to those of us in public agencies. I think the concern should not outweigh the satisfaction. There is great diversity in the available safflower germ plasm, and it remains largely unexplored. No one knows what potential may be found. Relatively little research has been done on safflower as compared to corn, wheat, soybeans, cotton, and perhaps other crops. There may be the possibility of developing greatly improved lines for use either as inbreds or as parents for commercial hybrids. Some of the most outstanding research in agriculture has been done by scientists of the ARS and the universities on corn, since the beginning of the hybrid corn industry. Similar opportunities will be available in safflower and other crops.

GENETICS OF SAFFLOWER SEED CHARACTERS RELATED TO UTILIZATION

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Safflower seed is utilized principally for its oil and protein content. The seed can be divided into two parts, hull and meat. The oil is contained exclusively in the meats, whereas the protein is mostly in the meats with a small amount in the hull. Botanically the hull is the pericarp and seedcoat, which is of maternal origin, whereas the meat is the embryo and its origin is both maternal and paternal.

Early genetic studies have shown that the greatest variation in oil percentage of the seed was obtained by varying the hull percentage. In other words, increased oil percentage was accomplished by making the meats a greater portion of the whole seed. In such investigations during the past 15 years, various mutant genes were found that greatly affected the hull characteristic. The most notable was my discovery of the thin-hull mutant in 1955 (1). About the same time Rubis and Thomas (2) identified the brown-striped mutant. More alleles at the striped locus have been discovered during the past several years.

Other genes affect the hull and meat characteristics. The "lt" gene conditioning light seedcoat color was found in an Indian

introduction at Mesa in 1953 and had special interest because of the light-colored oil extracted from these lines. In 1965 the pigmentless mutant gene "p" was discovered at Tucson. This gene prevents the formation of the melanin layer in the pericarp. Knowles and Hill (3) discovered two mutant genes which increased the oleic acid content of safflower oil.

We will consider a few of the genes affecting the characteristics of the hulls and meats and discuss briefly the botanical characteristics and chemical composition of some of the possible genotypes. We will also point out their relationship to agronomic usefulness and to final seed utilization. In addition to these individual genes, which we call major genes, there are many minor genes which may condition the same characteristics, which we call quantitative characters. Some major genes appear to act independently while others are modified by the genetic background, which in essence is many minor genes.

Genes affecting hull. First we will consider four loci affecting the hull. The genes or alleles are listed in order of dominance. These are as follows:

Thin-hull locus
- Th -- normal
- th -- thin-hull

Striped locus
- Stp -- normal
- stp^g -- gray-striped
- stp^p -- purple-striped
- stp -- brown-striped

Light-seed-coat locus
- Lt -- normal
- lt -- light seedcoat

Pigmentless locus
- P -- normal
- p -- pigmentless

Any single plant of a line, variety, or hybrid variety may be made up of any combination of two alleles at each locus to form a certain genotype. For example, the variety Gila is of the following genotype: ThTh, StpStp, LtLt, PP and is considered normal in our classification. Generally various genotypes are identified only by the genes that are mutant. For example, thth, StpStp, LtLt, PP is simply called a thin-hull line and ThTh, stpstp, LtLt, pp is called a pigmentless, brown-striped line.

The mutant genes at these various loci have very definite characteristics different from the normal. A normal hull, such as that of Gila, consists of the following tissue (from outside to inside) (4):

- epidermis
- hypodermis
- outer sclerenchyma
- phytomelanin layer
- inner sclerenchyma
- outer epidermis of seedcoat
- parenchymous layer of seedcoat
- inner epidermis of seedcoat
- endosperm

The outer and inner sclerenchymas make up about 60 percent or more of the mature hull and are the white, highly lignified tissue causing the seed to appear white. The sclerenchyma is divided by a continuous pigmented layer called the melanin layer, which is reddish-brown. The seedcoat is about 15 percent of the entire hull, is made up of two epidermal layers, and is brown. The epidermis, hypodermis, parenchymous layer of the seedcoat and endosperm is usually only a few cells thick.

The principal characteristics of the mutant hull types are as follows:

thth -- Because of the non-lignification of the outer sclerenchyma cells at maturity, the melanin layer shows through the sclerenchyma layer, causing the seeds to appear gray or brown. The hull is greatly reduced in thickness and weight and results in seeds of higher oil and protein and lower hull percentage (table 1).

Table 1.--The average percentage of hull, oil, protein, and fiber in safflower seed of several genotypes

Genotype	Hull	Oil	Meal	
			Protein	Fiber
ThTh StpStp	40	39	20	41
ThTh stpstp	25	46	34	25
thth StpStp	20	47	40	17

$stp^{g}stp^{g}$, $stp^{p}stp^{g}$, stpstp -- The gray-striped (stp^{g}) mutant is a result of a variation in the thickness of the outer sclerenchyma layer, causing the melanin layer to show through as gray stripes. In the purple-striped (stpP) the melanin layer is partly localized in canals and the sclerenchyma varies in thickness as in the gray-striped. In the brown-striped (stp) the melanin layer is localized in definite canals and the lignification of the sclerenchyma, which is very thin, is restricted to the regions above and below these canals. The brown-striped seeds have a greatly reduced hull percentage, accompanied by increased oil and protein percentages. However, the brown-striped seeds have a wet-strawlike odor and the oil extracted from the seeds is darker in color.

ltlt -- Seeds with light seedcoats (lt) are a light tan to yellowish, in contrast to brown in the normal. The extracted oil is usually lighter in color.

p p -- The pigmentless genes prevent the formation of the melanin layer. Gila seeds appear chalk white instead of shiny white. Thin-hull (th th) and all striped-hull seeds are white in appearance. Seeds which are pp, lt lt appear yellowish, produce lighter-colored oil, and as Kemmerer (5) points out may have improved oil stability.

Genes affecting meats. Fewer major genes have been identified which affect oil characteristics. The reason, I believe, is not because they do not exist, but because fewer studies have been conducted. Knowles and Hill (3) have reported varying the fatty acid composition of the oil. Their most notable work has been the production of the high oleic acid lines. They discovered three alleles at one locus which had the following effect on the amounts of linoleic and oleic acids in safflower oil:

	Linoleic acid	Oleic acid
0101	-- 75 to 85 percent	10 to 15 percent
$ol^{1}ol^{1}$	-- 42 to 54 percent	35 to 50 percent
ol ol	-- 12 to 30 percent	64 to 83 percent

The higher oleic genes (ol) were found to affect also the stability of the oil (5).

Quantitative genetics. In quantitative genetics characteristics are evaluated by measurement such as oil percentage and hull percentage rather than by genotypic classification. Quantitative characters vary because of both minor genes and environmental factors, and the amount of variation due to each is a typical genetic problem. We have discussed a number of major genes affecting hull characteristics; however, in comparison there are many more minor genes affecting hull percentage (6). Consider, for example, the compositions of typical normal, striped, and thin-hull lines in table 1. These same genotypes in varying genetic backgrounds will vary considerably. Normal hull lines may vary from 30 to 60 percent hull and thin-hull lines from 17 to 35 percent hull. This variation is possible mostly because of quantitative genes. In table 2 we show the advantage of certain major genes in hybrids over pure-line varieties and of certain alleles over other alleles at the same loci in reducing hull percentage. However, these values are means with a variance of $\pm$ 5 percent or more. Therefore, in practice we can select the genotype with the desired quality factors and then select for reduced hull percentage within that genotype.

There are many seed characters conditioned by quantitative genes from which we can select in a breeding program. The oil percentage of meats will vary from approximately 50 to 70 percent

and the protein percentage from 18 to 30 percent. There are quantitative genes affecting the melanin layer. In fact, I'm sure there are genes affecting most characteristics if only we had procedures for measuring them.

Table 2.--Expected hull percentages of several genotypes when used as varieties or hybrids as calculated from F_2 segregating populations

		Variety		Hybrid	
		F	M	F	M
F	M	Th	Th	th	Th
Stp	Stp	36.6		34.4	
stp^g	stp^g	36.5		34.2	
stp^g	stp	34.3		32.7	
stp	stp	24.7		23.9	

Future. A plant breeder-geneticist can fabricate by genetical control a safflower seed of almost any composition if an economical and efficient procedure, analytical or otherwise, is available to evaluate large numbers in a population. The amount of variation in safflower in all characteristics is extremely large, and we have used to date only a small amount of this variation. Great strides have been made in improving the quantity of oil and protein. We must now decide at what level production and utilization are most economical. Future research must concentrate on oil and protein quality; but here there is great need for the establishment of standards and techniques for evaluation. I believe the future progress lies in a close cooperation of geneticist-breeder and chemist-nutritionist in the development of analytical procedures and the discovery or development of new genetic types to fulfill future needs.

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SAMPLING AND ANALYSIS OF SAFFLOWER SEED

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A new method of analysis for safflower seed oil content has been developed to simplify the procedure involved and improve its precision. The method consists of grinding the seed sample with an equal amount of diatomaceous earth in a high-speed mill and then extracting the ground mixture in a Butt-type extractor.

The analysis of any oilseed starts with the taking of a proper sample. At our plant, truck and railroad hopper cars are normally sampled with a slotted tubular seed probe at 5 to 6 points. Where seed has a vertical fall from a pipe, a pelican sampler can be used to cut the entire stream of seed. Samples are taken at regular intervals throughout the loading or unloading operation. The large composite sample is split to suitable size with a Boerner splitter or a riffle.

Safflower seed is usually sold on a clean-seed basis--that is, 100 percent minus dockage or foreign matter. Dockage can be determined by one of two methods. AOCS Ag 1-65 specifies cleaning 100 grams of seed with hand sieves and the Bates aspirator. It has been found that a 1,000-gram sample will give better duplication. The weighed 1,000-gram sample is first sifted over aluminum sieves. The material that remains on top of the sieves is then passed through the Bates aspirator to remove light foreign matter and unfilled seeds by means of a fan. The seed must be recycled through the aspirator until essentially all the blanks are removed. This is a very important step. Some samples may require 20 to 30 passes. Any remaining foreign matter is then hand-picked from the sieved and aspirated sample. The total dockage finally consists of the material that passed through the fine sieve, the fraction removed by aspiration, and the hand-picked material.

A much faster and easier way to run a dockage test on safflower seed is to use a properly modified Carter dockage tester. Here we have the same sizes of sieves as before along with a fan

to remove the blanks and light materials. A 1,000-gram sample is weighed into the machine and is cleaned in one pass in about 3 minutes. A part of the machine-cleaned seed is hand-picked for dockage as before.

The hand-picked clean seed sample from either cleaning method is now ready for further analyses. Moisture is determined by drying 10 grams of seed for 2 hours at 130°C. in a forced-draft oven.

American Oil Chemists' Society method Ag 1-65 for safflower seed oil content calls for carefully grinding 10 grams of cleaned seed with a steel mortar and pestle and then extracting for 4 hours with petroleum ether and a Butt extractor. The extracted seed is then reground with a little sand in a Coors mortar, returned to the extractor, and extracted for 4 more hours. This method can give low results if the grinding is not complete.

In an effort to reduce the time and labor involved in a safflower seed oil content analysis and to try to improve the reliability of the test, a new method using diatomaceous earth and a high speed grinder has been proposed. In 1966 this method was used by 15 laboratories on a set of five samples in a program sponsored by a committee of the AOCS.

Safflower is very difficult to grind properly. Most mechanical grinders either grind the seed inadequately or smash the seed into something with the consistency of peanut butter. A high-speed grinder was found that would give the seed a fairly fine grind when it was first mixed with an equal amount of diatomaceous earth or filter aid. The resulting mixture is a dry free-flowing meal which is easily and completely removed from the grinder by means of a brush.

The following is a description of the method and equipment: The grinder is a High Speed Grinder, Model A-1 rated at 23,000 r.p.m., manufactured by High Speed Blending & Mixing Corp. Fifteen grams of cleaned seed are added to the cap, followed by 15 grams of filter aid. The grinder is attached to the lid and the seed is ground for 40 to 45 seconds while the grinder is tilted back and forth. At this point about 85 percent of the ground mixture will pass through a 20-mesh screen. The ground mixture is brushed to a sample pan and then to a lidded can. After thorough mixing in the can, 10 grams are weighed on a piece of 15-cm. filter paper.

The weighed sample, with the paper wrapped around it, is placed in a paper extraction thimble. The thimble is placed in a Butt extractor connected to a tared flask containing pet ether. The sample is extracted for 4 hours. The pet ether can be removed from the flask by evaporating on a steam or water bath to constant

weight. In our laboratory we evaporate on a hot plate controlled at just under 100°C. for 1 1/2 hours while a gentle stream of nitrogen is used to remove the solvent. After cooling in a desiccator, the flask is weighed and the oil content calculated.

Table 1 shows the results of a collaborative study of the new method for safflower seed oil content. One lab used the mortar-and-pestle method, six used the A-1 grinder with filter aid, while the rest used other grinders but otherwise adhered to the new method. As shown on the second line the oil content range for each sample varied from 1.6 to 2.9 percent, while the standard deviation varied from 0.5 to 0.7. There was no apparent difference between the grinding methods.

Table 1.--Smalley collaboration checks on safflower seed (15 collaborators)

Item	Sample A	B	C	D	E
Range	37.0 to 39.0	37.6 to 39.3	37.3 to 40.2	46.2 to 48.2	42.2 to 44.8
Average	38.2	38.3	38.3	47.0	43.4
Std. dev.	0.5	0.5	0.7	0.6	0.7

At this point, it might be well to look at some of the factors that can result in differences in oil content between analysts. First, sampling is important. The sample must represent the average of the whole lot if we expect, for instance, a receiving analysis to match a shipped analysis. Next the cleaning step is important. All dockage must be properly removed. On some samples removal of blanks may have to be rechecked. Slow tumbling of the cleaned seed sample prior to sampling the charge for the grinding step is necessary to avoid pockets of fines, odd-sized seeds, or odd-density seeds which may have oil contents varying tremendously from the average of the whole sample. It is important to know that the diatomaceous earth contains nothing extractable and that it doesn't hold the oil in the extraction step. One sample of filter aid tried in our laboratory gave a result about 2 percent low in the 40 percent oil range and gave an extracted oil that had a much lighter color. It has been suggested that the amount of seed used in the grinding step is too small. A larger sample may cut down the sampling error.

We are now evaluating the factors already mentioned and some other factors that may have caused variance--for example type of grinder (no effect?), type of solvent, humidity, type of earth, and solvent removal. Each may contribute to the experimental error. We did succeed in simplifying the test method. We eliminated one regrind and one 4-hour extraction and two rather

arduous hand-grinding procedures. Overall we do have a very usable analysis that gives good reproducibility when performed by an experienced analyst.

A bonus of the new grinding system is that the ground sample can also be used for accurate seed protein determinations by the Kjeldahl method. High-oil seed may give low protein results unless sample size is kept small or unless the oil is removed first.

COMPOSITION OF SAFFLOWER SEED

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After oil is removed from safflower seeds of the common commercial varieties, the remaining meal amounts to 60 percent or more of the weight of the original seed. (All composition figures are on the moisture-free basis.) The new, essentially experimental thin-hull varieties yield 50 to 55 percent meal. Meals from thick-hull varieties are 25 to 30 percent protein and those of thin-hull seed are up to 40 percent protein. Both should be valuable in animal rations.

The oil processor, however, has failed to receive the actual value of his safflower residue. The main reason is, of course, the high fiber content. Another reason is lack of information on other feed values of the seed. Two approaches are solving the high-fiber problem. One is partial decortication (hull removal) by the oil processor; the other is the development of new varieties of seeds with less hull. If all the hull is eliminated, the resulting oil-free kernel has about 65 percent protein, whether from thick- or thin-hull seed. Little information is now available on composition of the other 35 percent of the defatted kernel. Until its composition is known, feed manufacturers will be reluctant to pay much for it. During the past 3 years, we have analyzed a few samples of safflower seed and meals for various chemical constituents. I will present some of the data and describe our plans.

We have carefully hand-separated the kernel from the hull of 23 samples of seed of various types and sources. From Paul F. Knowles of University of California, Davis, we have obtained three commercial thick-hull samples, one experimental, one with thin-hull seeds, and three plant introductions from Southwest Asia with unusual oil characteristics. From David D. Rubis of University of Arizona, Mesa and Tucson, we have received seven samples of brown-

striped seeds, two of thin-hull, and one of pigmentless brown-striped seeds. Dr. Rubis also furnished five samples of thick-hull varieties. These seeds were split by a device manufactured in our own shops or by a more complicated commercial model. The kernels and hulls were carefully hand separated and weighed.

Table 1.--Kernel and hull of safflower seed and meal

Type	Number of samples	Whole seed			Oil-free meal	
		Kernel	Hull	Oil	Kernel	Hull
		Pct.	Pct.	Pct.	Pct.	Pct.
Gila	4	62.0	38.0	38.1	38.6	61.4
U-5	1	63.9	36.1	38.5	41.3	58.7
US-10	1	63.3	36.7	36.8	41.9	58.1
Frio	1	64.6	35.4	40.1	40.9	59.1
Southwest Asia	3	48.8	51.2	25.9	30.9	69.1
Hybrid thick-hull	2	63.6	36.4	37.8	41.5	58.5
Pigmentless brown-striped	1	74.7	25.3	42.8	55.8	44.2
Brown-striped	8	74.1	25.9	47.7	50.5	49.5
Thin-hull	3	76.0	24.0	47.2	54.5	45.5

Table 1 shows the percentages of hulls and kernels before and after removal of the oil. The "after" figures are calculated where there was more than one sample of a type; the results were averaged. Table 2 shows the distribution of constituents in the different types of seeds. NFE (nitrogen-free extract) is merely the difference between 100 percent and the sum of the other four fractions. Later I will discuss each of these fractions. Table 3 shows the distribution of the same fractions in the clean hull. The oil shown is mostly due to unavoidable contamination from the kernel. Of interest is the higher ash and protein contents of the thin-hull varieties. If the ash were concentrated in the inner layers of the hull, it would account for the lower percentage in the thicker hulls. It is doubtful that the protein of the hulls would be available for animal nutrition because of the large amount of lignin present (which we will get to later) and lignin's notorious ability to make protein nutritionally unavailable.

Table 4 shows the distribution of fractions in the hull-free kernel. The large amount of oil present is easily seen here. If the oil is removed completely (table 5), this is the calculated distribution of the fractions of the whole seed. It can be seen here that there is more protein in the oil-free meal from thin-hull seeds than there is from thick-hull seeds. The reason is that there is less hull in meal from thin-hull seeds.

Table 2.--Whole safflower seed (moisture-free basis)

Type	Number of samples	Oil	Protein	Fiber	Ash	NFE
		Pct.	Pct.	Pct.	Pct.	Pct.
Southwest Asia thick-hull	3	25.9	18.4	32.6	2.5	20.6
Gila	4	38.1	16.7	22.3	2.6	20.3
U-5	1	38.5	17.2	21.1	2.3	20.9
US-10	1	36.8	19.4	22.3	2.5	19.0
Frio	1	40.1	15.4	20.8	2.3	21.4
Thick-hull hybrid	2	37.8	17.3	21.5	0.7	22.7
Brown-striped	8	47.7	20.3	11.7	3.4	16.9
Pigmentless brown-striped	1	42.8	22.5	13.6	3.5	17.6
Thin-hull	3	47.2	21.1	11.2	3.3	17.3

Table 3.--Hull (moisture-free basis)

Type	Number of samples	Oil	Protein	Fiber	Ash	NFE
		Pct.	Pct.	Pct.	Pct.	Pct.
Southwest Asia thick-hull	3	2.2	4.1	63.9	0.9	28.9
Gila	4	3.2	4.3	57.1	2.0	33.4
U-5	1	2.2	5.0	58.4	1.4	33.0
US-10	1	1.4	3.8	60.0	1.6	33.2
Frio	1	2.7	4.1	60.4	2.2	30.6
Thick-hull hybrid	2	2.2	4.1	63.9	0.9	28.9
Brown-striped	8	5.7	8.4	46.9	4.9	34.1
Pigmentless brown-striped	1	5.6	8.6	46.2	5.1	34.5
Thin-hull	3	5.1	10.0	45.3	5.1	34.5

Table 4.--Kernel (moisture-free basis)

Type	Number of samples	Oil	Protein	Fiber	Ash	NFE
		Pct.	Pct.	Pct.	Pct.	Pct.
Southwest Asia thick-hull	3	52.2	34.3	1.5	4.2	7.8
Gila	4	60.9	24.9	1.6	3.1	9.5
U-5	1	61.8	25.4	1.5	2.9	8.4
US-10	1	59.0	29.4	1.5	3.2	6.9
Frio	1	64.0	23.0	1.0	2.6	9.4
Thick-hull hybrid	2	58.1	24.7	2.8	3.1	11.3
Brown-striped	8	62.7	24.8	0.9	3.1	8.5
Pigmentless brown-striped	1	55.9	27.4	2.7	3.1	10.9
Thin-hull	3	62.6	25.5	0.9	3.0	8.0

Table 6 shows the composition of the completely hull-free, completely defatted kernel. This is the optimum low-fiber product that should be the processor's goal if he is to get the best price for his residue. It is evident that once the hull and oil are removed, the protein content of the thin-hull kernel is little, if any, different from that of the thick-hull seed.

Table 5.--Oil-free whole seed (moisture-free basis)

Type	Number of samples	Protein	Fiber	Ash	NFE
		Pct.	Pct.	Pct.	Pct.
Southwest Asia thick-hull	3	24.8	44.0	3.3	27.9
Gila	4	27.0	35.9	4.2	32.9
U-5	1	28.0	34.3	3.7	34.0
US-10	1	30.7	35.3	4.0	30.0
Frio	1	25.7	34.7	3.8	35.8
Thick-hull hybrid	2	27.7	34.5	4.3	33.5
Brown-striped	8	38.6	22.4	6.6	32.4
Pigmentless brown-striped	1	39.3	23.8	6.1	30.8
Thin-hull	3	40.0	21.2	6.4	32.4

Table 6.--Oil-free kernel (moisture-free basis)

Type	Number of samples	Protein	Fiber	Ash	NFE
		Pct.	Pct.	Pct.	Pct.
Southwest Asia thick-hull	3	71.8	3.2	8.8	16.2
Gila	4	64.0	4.1	7.9	24.0
U-5	1	66.4	3.9	7.5	22.2
US-10	1	71.7	3.7	7.7	16.9
Frio	1	65.6	2.8	7.3	24.3
Thick-hull hybrid	2	58.3	6.6	6.8	28.3
Brown-striped	8	66.4	2.4	8.3	22.9
Pigmentless brown-striped	1	62.2	6.0	6.9	24.9
Thin-hull	3	67.8	2.3	7.9	22.0

The proximate scheme of analysis has been used for a century by animal nutritionists and gives a usable indication of the nutritional value of feedstuffs. It, however, tells us very little of the actual composition of the plant material. For example, some of the chemical components that are lumped together under the various headings are shown in table 7. Each of these individual components

has a different feed value. Some are inert; some, such as lignin and plant gums, exert a negative influence. Some furnish the energy the animal must have. And those components that have nutritive value differ in their degree of digestibility by different animals.

Table 7.--Proximate analysis fractions

Crude fat	Crude fiber	Nitrogen-free extract
Free fatty acids	Cellulose	Free sugars
Fatty acid glycerides	Lignin	Starch
Glycolipids	Pentosans	Pentosans
Lipoproteins	Hexosans	Hexosans
Phospholipids	Protein	Anhydro-uronic acid
Free sterols	Ash	Saponins
Sterol esters		Organic acids
Sterol glycosides		Degraded cellulose
Waxes		Lignin fragments

To obtain a better understanding of composition, we have determined crude fat, protein, ash, lignin, pentosans, total sugars, and anhydrouronic acid on four samples of meal, one of hull, and one of kernel. The hull and kernel were prepared here from brown-striped seed; three of the meal samples are partly decorticated and are from thick-hull seed; the other meal is undecorticated and is from brown-striped seed. Protein in plant materials is calculated by multiplying the percentage of nitrogen by the factor 6.25 (5.7 in the case of wheat). We have calculated the protein factor for safflower seed from amino acid analyses and have found that it is 5.42. We have used that factor for our summative analyses. Cellulose has been determined by a method originated here. A fiber residue is prepared from the sample by defatting with benzene-alcohol, and then extracting the defatted residue with dilute ammonium oxalate. The dried doubly extracted residue is analyzed for crude fat, protein, pentosans, lignin, and ash, and the sum of the percentages (of the original sample) of these is subtracted from the percentage fiber residue to give percent cellulose. Table 8 shows the distribution of the individual components.

Sugars were determined qualitatively by paper chromatography. Sucrose and raffinose were present in approximately equal amounts and there was no indication of either fructose or glucose. Defatted hull-free kernels were 4.3 percent total sugars, of which 0.32 percent were reducing sugars.

When the protein, lignin, pentosans, ash, fat, and anhydrouronic acid, total sugars, and cellulose were totaled, there was still 11.0 percent of the meal samples, 1.4 percent of the hull, and 15.5 percent of the kernel unaccounted for. Negative results

Table 8.--Safflower seed composition (moisture-free basis)

Type	Number of samples	Protein (N x 5.42)	Total sugars	Residual fat	Anhydro-uronic acid	Pentosans	Cellulose	Lignin	Ash	Missing
		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Partially decorticated thick-hull seed meal	3	42.1	4.7	1.5	1.1	9.5	14.7	7.6	7.8	11.0
Undecorticated brown-striped seed meal	1	34.1	3.3	1.5	2.5	10.4	18.9	11.6	6.6	11.1
Defatted brown-striped seed kernel	1	6.9	1.1	11.5	2.5	18.5	32.1	21.5	4.5	1.4
Brown-striped seed hull	1	51.0	7.6	1.0	1.1	4.6	6.1	3.2	9.9	15.5

of numerous potassium iodide-iodine tests indicate that safflower kernel has no starch. The missing fraction probably includes organic acids, noncellulosic hexosans, phenolics, or other constituents which may each be present in small amounts. Whatever it is, it makes up a large enough fraction of the potentially valuable part of the safflower seed residue so that it should be investigated further.

COLOR PROBLEMS IN SAFFLOWER OIL

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Breeding work on safflower is directed mainly toward higher oil content and meal protein. The University of Arizona, the U.S. Department of Agriculture, and the Western Cotton Products collaborated in the development and experimental planting of a line of safflower seed which has a higher than normal percentage of oil. This line of seed, which is characterized by brown stripes, contains about 47 percent oil, compared to a normal of about 36 percent, and contains higher protein and lower fiber in the remainder of the seed. Pilot plant work was performed to determine whether normal oil processing methods would produce an edible oil from brown-stripe seeds. The conclusions were that normal refining and bleaching did not produce an oil comparable to domestic safflower oil. The experimental oil was darker and the characteristic strawlike odor carried through refining and bleaching. Deodorization apparently removed the odor, at least temporarily, but brown-stripe oil remained much darker than commercial oil.

The work reported here, concerned with the nature and removal of this dark color, produced results that allow production of an oil comparable to the commercial product. The dark pigment is formed upon heating from a colorless precursor. This color precursor is present in both extracted commercial and brown-stripe oil but much larger amounts are present in the latter (table 1). If temperatures during oil processing are in excess of 100°C. for extended periods, this precursor condenses to a reddish brown pigment which at higher concentrations cannot be removed completely by means of normal oil refinement procedures. If temperatures during processing are kept below 100°C. no pigment formation occurs (table 1). The color precursor present in the extracted oil can then be removed by extraction with water or through normal alkali refinement, after which heating for extended periods at high

Table 1.--E-values for unrefined safflower oil samples

Item	Pressed	Extracted after pressing	Extracted only
Commercial seed - hot	0	0.04	--
Brown-stripe seed - hot	0	.12	--
Brown-stripe seed - cold	0	0	0.00
Brown-stripe, kernels only	0	.42	--
Brown-stripe, hulls only - hot	--	--	0.02

temperatures causes only bleaching. (The bleaching is the result of heat decomposition of the yellow pigment present in all unrefined safflower oils.)

No color precursor was found in press oil of commercial or brown-stripe seed even when pressed at temperatures of 130°C. When the resulting press cake was extracted with cold hexane, no color precursor was found in the obtained oil (table 1). With this procedure (pressing below 130°C. followed by extracting at room temperature) all the oil of brown-stripe seeds can easily be obtained without either pigment or pigment precursor. Oil from brown-stripe safflower seeds rich in dark pigment can be completely decolorized and refined in one step by treatment with 2 percent of a 2-normal solution of potassium hydroxide containing 3 percent hydrogen peroxide. The E-value before treatment is 0.37, after treatment 0.00.

The qualities of safflower oil samples in respect to the presence of pigment precursor were measured by means of their optical density at a wavelength of λ = 550 mμ. For standardization purposes, E values were chosen which were obtained with a 1 mm. pathlength by using the neat oils after heating for 2 hours at 160°C. Under these conditions pigment-free or almost pigment-free oils have values of E = < 0.01. Water extraction (1:1 water:oil) or normal alkali refinement lowered E-values of all samples containing color precursor to E = 0.00 (table 2). A more detailed report on this work has been submitted for publication in the Journal of the American Oil Chemists' Society.

Table 2.--Removal of color precursor by water extraction or standard alkali refinement (E-values)

Item	Before removal, heated	After removal, heated
Brown-stripe, hot extracted kernels	0.42	0
Brown-stripe, whole seeds, hot extracted	.12	0
Commercial seeds, hot extracted	.04	0
Brown-stripe, hot extracted hulls	.02	0

ODOR PROBLEMS IN SAFFLOWER OIL

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The high oil content--45 to more than 50 percent--of thin-hulled brown-stripe safflower seed and yield per acre equivalent to commercial seed make this variety attractive for commercial development. This oil content is nearly one-third greater than that of the present commercial seed. Unfortunately, the extracted oil has a sturdy, unpleasant smell. This smell reportedly can be removed during processing, but with storage the oil reassumes an objectionable odor.

The smell is quite complex. This can be shown by gas-liquid chromatographic analyses of odor concentrates. There are stinky, floral, musky, cedary, grassy, and beany odor components and probably nearly 100 compounds contribute significantly to the composite smell.

A test which apparently can be used to indicate the presence and likely intensity of brown-striped seed odor constituents involves the appearance of a blue spot following thin-layer chromatography of nonsaponifiables. When developed on a chromatostrip with 30 percent ether in Skellysolve F, 150 µg. loads of nonsaponifiables from several brown-stripe types sprayed with sulfuric acid, charred, then viewed under ultraviolet light showed brilliant blue spots at R_f 0.60. Nonsaponifiables from the nonsmelly Gila variety do not show this spot and in a hybrid variety it is attenuated.

Where do the odors come from? They come from the hulls. Neither kernel oil nor acids and nonsaponifiables derived from it have objectionable odors. But hulls extracted with Skellysolve F give 4-1/2 percent of light orange oil with strong smell. Alkali extraction of this hull oil removes a small amount of very stinky material and leaves the oil with a predominantly cedar odor. When the alkali-extracted oil is chromatographed on silicic acid, 85 percent of colorless, odorless glycerides is eluted first. Nonsaponifiables and acids from this fraction have little odor. The remaining 15 percent is eluted in yellow, green, and orange fractions--all with pronounced odors. Saponification of these fractions yields very stinky acids and nonsaponifiables with the musky, cedary, and grassy odors.

The stinky acids include butyric, isovaleric, pentanoic, hexanoic, heptanoic and heptenoic, octanoic and octenoic, and nonanoic acids. These constitute about 0.02 percent of the fatty acids of the whole seed oil. If there were 0.1 percent of free fatty

acids in the oil, there would be 1 part in 5,000,000 of stinky acids present. This is above the odor thresholds for these acids, but at this level is perceived as a heavy, unpleasant smell rather than as a stink. Partial hydrolysis of alkali-refined oil would bring back the offensive smell, and this is probably the reason for the recurring smell. The odoriferous components of the nonsaponifiables have been partly characterized but not identified.

After hulls are extracted with Skellysolve F, further extraction with acetone gives a viscous orange liquid with a high concentration of the characteristic offensive smell. This is another indication that the objectionable odors come from relatively polar seed components and suggests that cold extraction of seed oil with petroleum ether will yield a less smelly oil than hot extraction. After the smell is in the oil, bleaching plus steam stripping can remove it and probably prevent its recurrence.

When small samples of brown-striped seed oil were bleached at about 220°F. for 15 minutes with 5 percent by weight of both the natural and acid activated official bleaching clays and Special Filtrol No. 4, the recovered oil in each case was nearly colorless and had very little odor. Differences between the samples were insignificant. To test whether odor would be likely to return to these samples, they were saponified and the nonsaponifiables and free acids were sniffed attentively. In addition to their usual smell, the nonsaponifiables had a fragrant odor but did not have the cedar and grassy odors. The acid-activated bleaching clay was slightly more effective in removing nonsaponifiable odor components than the other agents. Free acids from the samples treated with the official bleaching clays had only traces of unpleasant odors. Both of these clays were more effective than Special Filtrol in removing the stink-generating component.

When a sample of brown-stripe seed oil was subjected to a steam distillation under vacuum, the oil recovered was the same color as the original oil but was odorless. Nonsaponifiables from this oil have a light fragrant and floral odor that is inoffensive. However, the free acids have a very strongly stinky smell. The steam-stripped oil was then bleached with 4-1/2 percent of the acid-activated bleaching clay. Neither the recovered oil nor nonsaponifiables and free acids derived from it had more than a merely detectable amount of smell.

These experiments thus indicate that the objectionable odors can be removed from the oil and that the odor-regenerating components can probably also be removed. Large amounts of steam and bleaching earth were used--more than would be desirable in industrial processing--merely to determine the possibility of effective deodorization. The amount of bleaching earth necessary is the amount that will

remove the most polar 0.7 percent of the whole seed oil and thereby remove the odor-regenerating components. In my steam-stripping operation, an amount of steam larger than the oil sample was used, but certainly far less would be adequate. Use of a high vacuum is desirable because many of the odoriferous components have high boiling points.

With the results of the bleaching and deodorization procedures in mind, I think the odor of the extracted oil need not be a deterrent to commercial development of brown-stripe safflower seed.

THE COMPOSITION OF SAFFLOWER OIL

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This presentation briefly reviews the compositions of some experimental and commercial safflower seed oils. Much of the work was reported in a 1966 publication in the American Oil Chemists' Society's Safflower Symposium. Some additional information has been included from recent literature.

One of the most important features of safflower oil is its fatty acid composition. In table 1 are collected some results of fatty acid analyses on various experimental safflower oils. As will be shown, the composition of the high linoleic oils is essentially indistinguishable from that of the normal commercial oils. Note that these nonsaponifiable figures have a high degree of uncertainty because of the very small sample sizes used. The fatty acid results, for the most part, however, were determined by gas-liquid chromatography (GLC) on the esters and are quite reliable. The other experimental results are quite interesting. Horowitz and Winter (10) in 1957 described the high-oleic types. Since then, Knowles and coworkers (15,16) have reported and further developed both the high-oleic and intermediate types. They also have described the so-called high stearic types (see last line). With only about 10 percent stearic acid, the high stearic certainly does not promise to substitute for tallow; however, the high-oleic types should eventually be an excellent source of oleic acid. As is true with regular safflower, however, this type of seed must compete economically with other farm commodities for acreage. Some selected results on commercial safflower oils appear in table 2.

Classical methods were used to obtain the data on the first two lines while the remainder of the results were determined

Table 1.--Experimental safflower oil compositions
(G. O. Kohler and others supplied unpublished data in the first line and also those in parentheses. The latter are measurements on single samples from R. F. Knowles)

Seed type	Palmitic	Stearic	Oleic	Linoleic	Misc.	Nonsaponifiable	Reference
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	
High linoleic	6.0-6.8	2.1-2.9	9.8-12.7	77.5-81.0	0.2-0.8	0.8-1.4	--
Intermediate	5.0-5.5	1.2-1.4	45.1-47.3	46.5-48.2	(0.8)	(1.3)	(15)
High oleic	4-8		74-79	11-19	--	--	(10)
Do	4.5	(1.2)	86.8	8.7	(0.5)	(2.3)	(16)
High stearic	(6.2)	(9.5)	(11.9)	(71.0)	(1.4)	(2.1)	--

Table 2.--Commercial safflower oil composition
(G. O. Kohler and others supplied unpublished data in the last line)

Method	Palmitic	Stearic	Oleic	Linoleic	Misc.	Nonsaponifiable	Reference
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	
UV, IV, Cryst.	6.3	3.1	13.2	76.0	0.2	1.2	(1)
Dist., IV, UV	4.1-5.1	5.4-6.5	7.1-7.5	78.5-80.0	2.4-3.0	--	(4)
GLC	-- 11 --		13	76.0	--	--	(19)
Do	7.1-7.5	2.5-2.8	12.2-13.6	76.1-78.3	--	--	(8)
Do	6.2	3.1	10.9	79.8	tr.	--	(13)
Do	7.9	2.7	14.8	74.1	0.5	--	(3)
Do	6.7	2.7	12.9	77.5	0.06	0.5	(11)
Do	6.4-7.0	2.4-2.8	9.7-13.1	76.9-80.5	0.2-0.8	0.9-1.6	--

by GLC techniques. There is surprisingly good agreement in the first four columns. For the most part the ranges are narrow and show the quite uniform composition of the major safflower oil acids. There seems to be little question that the linoleic acid percentage for high-linoleic types is always between 75 and 80 percent and that the other fatty acids fall in narrow ranges as well.

The glyceride structure of safflower oil has been determined a number of times by various methods. There seem to be conflicting opinions in the literature as to the glyceride distribution. Until their work of 1966, the most convincing study was that of Schofield and Dutton in 1958 (26); by use of countercurrent distribution (CCD) they found that safflower oil glycerides follow a random distribution pattern. Their observations on the oil seemed well substantiated when they demonstrated that the patterns for natural glycerides and base-catalyzed randomized glycerides were identical. In a more sophisticated approach together with Evans and McConnell, however, they used CCD, lipase hydrolysis, and GLC to demonstrate that the distribution is more nearly approximated by a 1,3-random-2-random pattern.

Another area of interest to processors and users is that of minor constituents--the odds and ends that make an oil better or worse depending on one's point of view. In table 3 are listed some data from the literature on various minor components of safflower oil. The lower nonsaponifiable values are probably those

Table 3.--Minor safflower oil constituents

Constituent	Percent	Reference
Nonsaponifiables	0.5-0.6	(24)
Do	0.87-1.26	(5)
Do	0.41-0.57	(11)
Squalene	0.004-0.007	(12)
Phospholipids	1.1	(21)
Hydrocarbons	0.01	(18)
Sterols	0.36	(14)
Do	0.63	(23)
γ-Sitosterol	[1]8.2-8.7	(5)
Stigmasterol	[1]3.5-4.7	(5)
β-Sitosterol	[1]52.9-59.9	(5)
Unknown	[1]26.7-35.4	(5)

[1]Percent of total sterol.

from prepress oils while the higher results were undoubtedly obtained on solvent extracted oils. Phospholipid data on safflower are scarce. Purdy and coworkers (24) noted that solvent oil has about 2 percent gums. The other data are those of McKillican and Sims (21) who noted a 1.1 percent phospholipid level in safflower seed oil 40 days after flowering. Kuksis (18) studied hydrocarbons in oils and reported 0.01 percent but many of these are apparently lost during refining. Ibrahim and coworkers (11,12) noted 0.004 to 0.007 percent squalene. Total sterol figures were given by McKillican and Sims (21) in their maturity studies but their results seem high. The 0.36 percent sterols noted by Kiribuchi and others (14) and 0.63 percent total sterols found by Norcia and Rosenthal (23) seem more reasonable and are in line with the usual nonsaponifiable percentages found. Eisner and Firestone (5) did not give a total sterol percentage figure but they did determine the percentage of various sterols in the total. These authors also suggested that the various sterol compositions can be used to check oil adulteration. Although the sterols are interesting they do not seem to offer much in the way of potential recoverable value from the nonsaponifiables.

Another point that should be mentioned here concerns oil color. Safflower oil is normally low in color. The maximum Gardner value listed in ASTM specifications is 12, and after heat bleach 5. Purdy and coworkers (24) note that normal values are below 4. Such color is probably associated with the carotenes and other pigments in the oil. The only reference to safflower carotenes is that of Baszynski who reported 12.6 mg./ℓ. of β-carotene which he noted is among the higher values he observed in seed oils.

Table 4 presents data on the tocopherols in safflower oil. Tocopherol content is of interest from both stability and nutritional standpoints. Unfortunately, the spread of the data offers a wide choice of values. At Pacific Vegetable Oil Corp. a range of 500 to 700 µg. per gram has been found on over 20 samples using a modified Emmerie-Engle method. This is in line with much of the data on the table which for the most part also were obtained by the Emmerie-Engle procedure. Of course, different separation procedures were employed, some of them quite complex. I should mention that the most recent paper--that of Rao and coworkers (25) in 1965--reported only a single-step thin-layer-chromatography (TLC) separation followed by elution and an Emmerie-Engle measurement. Their control mixture results were quite convincing and recoveries of tocopherols added to safflower oil were 94 to 96 percent.

Because more and more attention is being devoted to minor constituents in fats and oils, some data on minor saturated fatty acids of safflower oil are gathered in table 5. Palmitic and

stearic were referred to earlier, but the others shown here were part of the miscellaneous category. The most complete analysis is that of Kuemmel (17) on line 1, but there is nothing extraordinary about this class of acids.

Table 4.--Tocopherols in safflower oil

Oil type	Tocopherol	µg./gram	Reference
Crude	Total	283-920	(22)
Refined	α	370	(20)
Refined	Total	248-492	(9)
Refined	α	226-426	
Crude	Total	311-453	
Crude	α	290-411	
Crude	Total	870-910	(25)
Crude	α	405-495	
Crude	β	--	
Crude	γ	160-234	
Crude	δ	200-259	
	Total	319-750	(27)

Table 5.--Minor saturated fatty acids of safflower oil

C12	C14	C16	C18	C20	C22	C24	Reference
< 0.01	0.12	6.5	2.9	0.36	0.22	0.14	(17)
--	0.07	6.7	2.5	0.5	--		(11)
--	0-0.4	4.1-5.1	5.4-6.5	0.5-1.0	0.5-1.2	--	(14)
tr.	tr.	6.2	3.1	tr.	--	--	(13)
--	0.3	7.9	2.7	0.2	--	--	(3)
--	tr.	6.3	3.1	0.2	--	--	(1)

In the case of the minor unsaturated acids (table 6), Kuemmel (17) also has given the most complete analysis and has established the positions of the double bonds in the various monoenes. He did not however clearly define the presence of linolenic acid. Because of recurring fallacious claims based on old data, the question of linolenic acid content in safflower oil deserves special comment. This acid oxidizes readily and has been implicated in vegetable oil color and odor problems, and thus it is not particularly desirable as an oil component. A most careful search for linolenic acid was made by Ibrahim and coworkers (11). They used both polar and nonpolar stationary phases in their GLC analyses and their data can be interpreted to mean that linolenic acid is absent. A peak conceivably containing linolenate was observed on the polar column. When the same sample was then examined on the nonpolar column, linolenic was not observed--only eicosenoic. A clue perhaps to earlier

Table 6.--Minor unsaturated fatty acids of safflower oil

16:1	18:1	20:1	22:1	24:1	18:3	Ref.
0.06	13.8(Δ9)	0.27(Δ11)	0.03(Δ13)	0.10(Δ15)	tr.?	(17)
0.01-0.02	7.1-7.5	0.3	0.2-0.9	--	0.1(conj.)	(4)
tr.	10.9	tr.?	--	--	--	(13)
--	12.9	0.5	--	--	0	(11)

reports of linoleic acid is contained in Craig's (4) results (table 6). The conjugated triene he observed probably arises from autoxidation of linoleic.

Finally, many of us are now being exposed more and more to safflower oil in our daily lives. It is comforting to know that in 1964 Goodman showed that among its many other attributes, safflower oil also is nonallergenic.

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THE RELATIONSHIP OF POLYUNSATURATED FATS TO LIPID METABOLISM AND ATHEROGENESIS

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More than 15 years have elapsed since the first report in the literature from our laboratory indicated that substitution of vegetable for animal fat in the diet results in a fall in the level of plasma cholesterol and phospholipids (2). After an initial period of rather vigorous disagreement, this report was confirmed by many investigators in many parts of the world (1). The major point of this paper will be to consider the mechanisms of this effect and some possible clinical implications. All of the studies have been carried out on human subjects under precisely controlled dietary and other conditions.

There is general agreement among clinicians as well as investigators that maintained elevation of plasma lipids, with particular reference to cholesterol, will result in acceleration of the over-all process of atherogenesis. The best evidence in support of this observation is the fact that precocious atherosclerosis such as heart attacks and intermittent claudication prior to age 40, with few exceptions occurs in individuals with one or another form of genetically predisposed hyperlipidemia. On the basis of such evidence it would seem reasonable to conclude that if one can choose between a dietary program which will maintain relatively low rather than high levels of plasma lipids, the former condition is preferable.

The plasma cholesterol is derived from two major sources: cholesterol in the diet and cholesterol synthesized in the liver and possibly in the intestinal wall. Recent studies by Wilson and Lindsey (3) and in our own laboratory indicate that, at least in most individuals, dietary cholesterol contributes a relatively small portion of the plasma cholesterol as compared to material that is synthesized endogenously.

Cholesterol and its oxidation products, bile acids, are excreted into the intestinal tract in bile. A very significant portion of cholesterol and bile acids is reabsorbed from the small intestine. That portion not reabsorbed represents gross loss from the body. It is obvious that if this total loss exceeds the total amount of cholesterol ingested plus cholesterol synthesized, the individual is in negative cholesterol balance and vice versa.

Methodology for measurement of absolute excretion rates of cholesterol and bile acids has been fraught with difficulty.

Consequently, there has been much disagreement as to whether intake of polyunsaturated as compared to saturated fats is associated with an absolute increase in excretion of cholesterol and its metabolites. A recent report from our laboratory (4), based on more than 3 years of work, indicates that substitution of polyunsaturated for saturated fat in the diet results in an absolute increase in excretion of cholesterol and bile acids in essentially all subjects studied. The magnitude of this increase varies considerably but is enough, and usually considerably more than enough, to account for the decrease in total plasma cholesterol which is associated with the change from saturated to polyunsaturated fat. The opposite statement is also true if the sequence is polyunsaturated to saturated dietary fat. Again, it is to be emphasized that all of these statements are based upon metabolic ward studies with patients consuming quantitatively constant formula diets over prolonged periods of time, with quantitative stool collections. The basic principles underlying the methodology are demonstrated in figure 1.

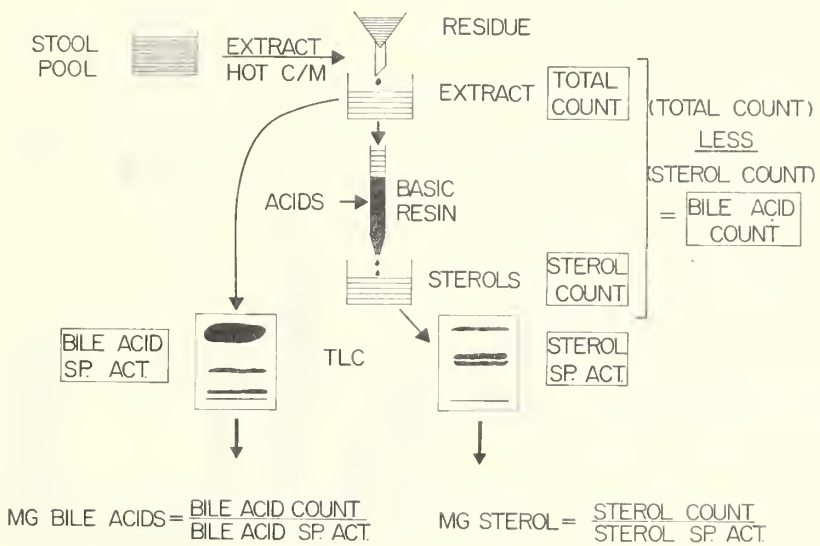

Figure 1. Diagrammatic outline of methodology used in "cholesterol balance" studies.

In figure 2 are shown two studies, the first with a subject in whom the initial dietary fat was trilinolein and the second molecularly distilled coconut oil (calories, protein, carbohydrates, etc. remaining constant). In the second study the reverse order was followed. The effect of the dietary change on total stool steroid excretion is obvious. Figure 3 is a summation of the results with the first seven subjects studied, indicating the magnitude of increase in stool steroid excretion with change from saturated to polyunsaturated fat.

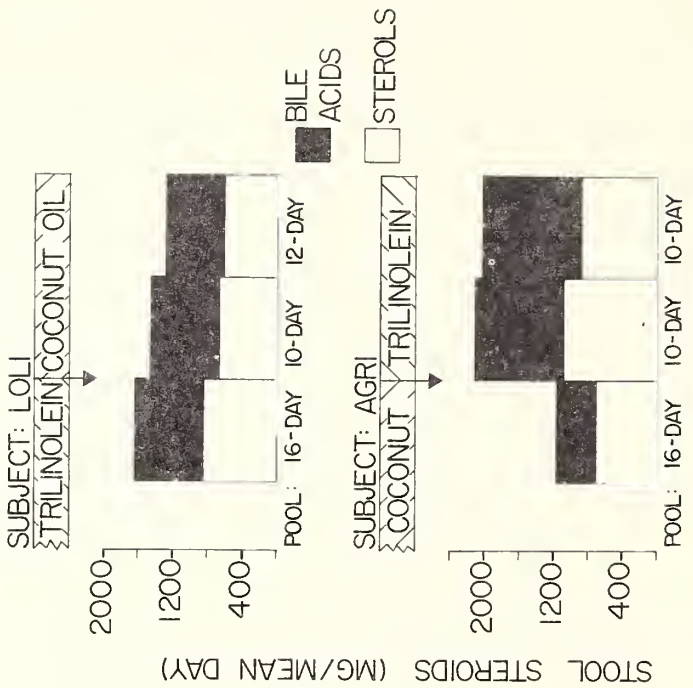

Figure 2. Effects of dietary fat on stool steroid excretion (cholesterol plus primary and secondary metabolites).

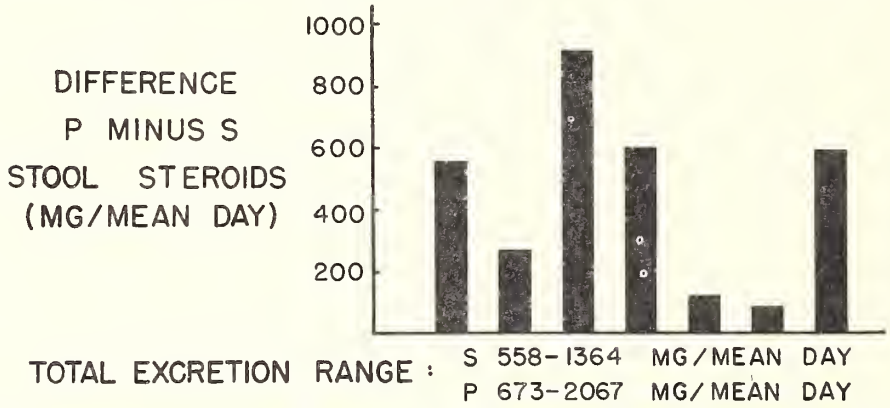

Figure 3. Net increase in stool steroid excretion with change from saturated to polyunsaturated fats in first seven patients studied.

Because the matter of relative and absolute contribution of dietary cholesterol to the plasma cholesterol has been subject to considerable controversy for some years, this subject has recently received considerable attention in our laboratory. Figure 4 shows a study in which, after a period on sterol-free intake, 750 mg. of cholesterol was added to the diet. The dietary cholesterol was labeled with tracer amounts of tritium. From the data it appears that something less than 15 percent of the plasma cholesterol is derived from dietary cholesterol even in the presence of this rather large amount of dietary intake. When the fat was changed

from saturated to polyunsaturated, the relative contribution of the dietary cholesterol declined. This is compatible with the observation of increased excretion of cholesterol and the concept of diminished reabsorption of cholesterol, of both dietary and endogenous origin, in response to polyunsaturated fat intake.

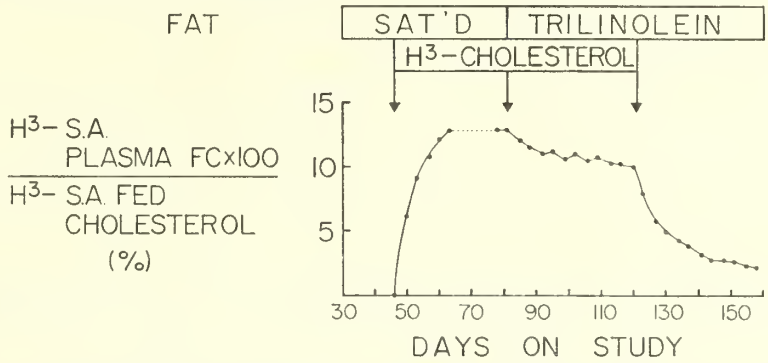

Figure 4. In normal subjects, dietary cholesterol is responsible for only a relatively small portion of the plasma cholesterol.

In figures 5 and 6 are shown portions of a long-term metabolic study in a subject in whom the specific activities of the plasma and bile cholesterol were measured throughout the study. After approximately 45 days the plasma cholesterol specific activity declined in an exponential fashion, indicating equilibration in all the miscible pools of the body. When the fat was changed from partly saturated to totally polyunsaturated, there was an initial abrupt fall in specific activity and then subsequent resumption of the same rate of decrease as that occurring previously,

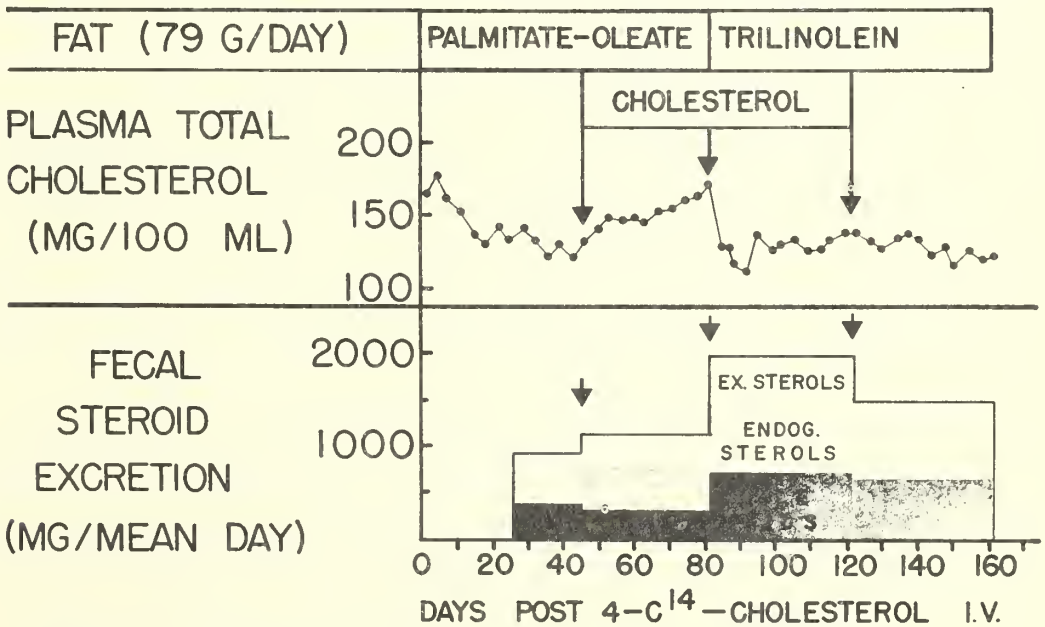

Figure 5. Effects of type of dietary fat on plasma and stool steroid levels.

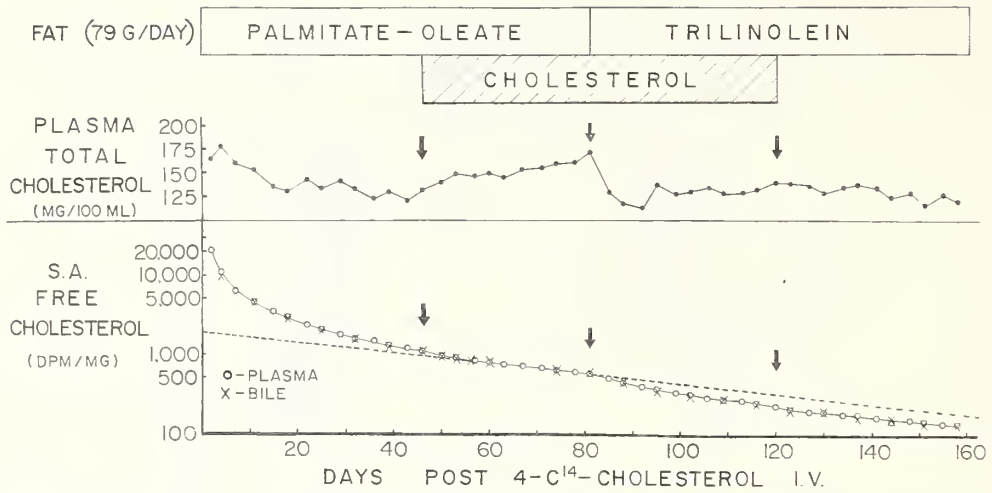

Figure 6. Effects of type of dietary fat on specific activity of bile and stool cholesterol.

despite the fact that the plasma cholesterol had fallen and then remained constant, but the excretion of cholesterol and bile acids in the stool remained elevated. The best interpretation of these findings appears to be that polyunsaturated fat has two major effects, namely, diminished reabsorption of cholesterol from the gut and increased mobilization of cholesterol from depots. Conceivably, and perhaps probably, such depots would include atheromata. These observations and concepts are undergoing further study at the present time.

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AUTOXIDATION AND ANTIOXIDANTS IN SAFFLOWER OIL

(Presented by A. R. Kemmerer)

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This presentation includes data from research on the oxidative stability of oils from various varieties of safflower seeds and on the natural antioxidants contained in these oils. The tabulations show only representative data, not all the data we have obtained.

The seeds were obtained from David Rubis, Department of Agronomy of the University of Arizona, and Paul Knowles, Department of Agronomy, University of California. Commercial oils were obtained from the Western Utilization Research and Development Division, USDA, the Pacific Vegetable Oil Corporation, and the Anderson Clayton Corporation.

The seeds were inspected for damage, for uniformity, and for anything that might affect their oil contents. They were then assayed for content of oil, free fatty acids, and crude protein. Table 1 shows the range of results. Oil content varies from 33.5 to nearly 47 percent. Seeds represented in the two lowest lines are recent crosses and are thin-hulled varieties. They also contain the highest amounts of protein.

Table 1.--Content of oil, free fatty acids, and protein in seeds

Kind of seed		Oil	Free fatty acid	Crude protein in seed
		Pct.	Pct. of oil	Pct.
VDL-641		33.5	0.05	-
Gila 65/2/1		34.2	.07	-
A104	White	35.0	.11	22.4
14154	Light brown	38.2	.11	33.0
A0104	White	39.6	.08	-
2050	Tan	46.8	.02	40.4
1998-A	Striped no pigment	46.9	.04	38.9

In our experiments considerable work had to be done on methods, as is usual when a project is started. The procedure used for extracting oil from the seeds, for example, greatly affected subsequent results. Briefly, our routine technique was to extract the seeds with petroleum ether (AR 30° to 60°C. ACS) in a blender decant, then swirl the contents with ethanol and water (10:160), add petroleum ether to this (180), and blend.

After filtration through a fritted disc, the alcohol was removed with water and the petroleum ether evaporated under vacuum. Oil samples were stored in dark containers in a refrigerator.

For determination of autoxidation the gain-in-weight method was used. One gram of oil was placed in a 30-ml. beaker painted black, covered with a black-painted watchglass, and then placed in a draft oven at 50°C. The beaker and contents were weighed daily. The induction period of the oil was considered to be the time from zero to the hour when there was a rapid weight gain. During this time insignificant amounts of oxidation had taken place. The induction period was determined as the time needed for the sample to gain 5 mg. in weight. At about this point the rate of oxidation changes from a relatively slow one to a comparatively fast rate of oxygen uptake. In statistical evaluation of results, a difference of 25 hours in induction period between oils is significant.

In some cases peroxide values were used to check the induction method. Peroxide values were determined on all the oils before they were placed on experiments. Weight gain and peroxide value were found to parallel each other.

Tocopherols were determined by the method of Emmerie and Engel as published by the Committee on Vitamin E (Analyst 84: 356-72, 1959). The oil was saponified after addition of pyrogallol by refluxing with alcoholic KOH for 3 minutes. The unsaponifiable residue was removed with peroxide-free ethyl ether. For total tocopherol the unsaponifiable residue was dissolved in benzene and subjected to the Emmerie-Engel reaction. In this reaction the tocopherols reduce ferric chloride to ferrous chloride and the ferrous chloride reacts with bipyridine to give a colored solution. The amount of color is determined by reading at 520 mμ. Alpha and gamma tocopherols were separated by thin-layer chromatography.

Table 2.--Induction period of oils

Kind of oil	Peroxide value	Induction period	Total tocopherol
	meq./kg.	Hours	μg./g.
A0104 White	<1.0	288	454
VDL-641 White	<1.0	372	635
A104 White	<1.0	434	586
1997-A Striped	4.0	441	560
2011-B Pigmentless light coated very thin hulled	<1.0	518	449
	<1.0	715	540

Table 2 shows induction periods and tocopherol contents of representative oils. Induction periods range from 288 to 715 hours

and tocopherol contents from 449 to 635 µg. per gram. There appears to be no correlation between length of induction period and tocopherol content. The major component in the total tocopherols is α-tocopherol. Only traces of γ-tocopherol are present. For comparison we separated the tocopherols from soybean oil and found a large proportion of γ-tocopherol. This same soybean oil had an induction period of 1,200 hours. As all of you know, γ-tocopherol is a better antioxidant than α-tocopherol.

As a means of elucidating the autoxidation of safflower oil, we investigated factors that affect the induction periods of the oil. Table 3 shows how addition of antioxidants affects the length of the induction period. Alpha or gamma tocopherol had no effect. Propyl gallate had appreciable effect.

Table 3.--Effect of addition of antioxidants to Gila 1862

Antioxidant added	Induction period
	Hours
None	135
0.01 percent α-tocopherol	112
0.10 percent γ-tocopherol	135
0.01 percent propyl gallate	811
0.10 percent propyl gallate	1,800

You may be concerned over the short induction period of the oil used for this experiment. This low value was probably due to the manner in which the oil was extracted from the seed. The only solvent used was petroleum ether. Thus only a small amount of phospholipid would be extracted and this could account for the low stability. We have had this same experience with other safflower oils.

Table 4.--Effect of refining upon induction period and peroxide value

Kind of oil	Induction period		Peroxide value	
	Refined	Crude	Refined	Crude
	Hours	Hours	meq./kg.	meq./kg.
A104	100	396	--	<1
12295 White	106	454	16.2	<1
2011-B	133	518	30.8	<1
Gila	468	576	21.5	2.7

Table 4 shows the effect of refining upon the induction period. The oil was refined by shaking with NaOH in water solution, centrifuging and decanting the oil. This would remove the free-fatty acids and at least part of the phospholipids. This method of refining significantly reduced the induction periods of the oil.

Table 5.--Induction periods at 37° and 50°C.

Kind of oil	Induction periods	
	37°C.	50°C.
	Hours	Hours
2134 Pigmented	772	240
2134 No pigment	864	260
1998 Pigmented	941	298
Gila 65/2/1	1,065	343

Table 5 shows that the temperature used for determining induction periods does not materially influence the results. At 37°C. the induction periods as would be expected are considerably longer than are the induction periods at 50°C. However, for both temperatures the order of oils as regards stability are the same.

Table 6.--Effect of mixing safflower oils on induction period

Kind of oil	Induction period	Tocopherol	Linoleic acid
	Hours	µg./g.	Pct.
UC-1	2,374	539	11
Gila	542	514	76
UC-1 + Gila (1:1)	787	511	45
UC-1 + Gila (3:1)	830	--	27
Intermediate iodine value	722	513	45

Table 6 gives some interesting data on the effect on induction period of mixing an oil with a long induction period with an oil with a much shorter induction period. In this case the oil with the long induction period had a high content of oleic acid. Mixing these two oils gave an oil with an induction period intermediate between the two. However, the induction period was lower than it should be as calculated from the proportions of the two oils in the mixtures.

Table 7.--Fatty acid composition of safflower oils

Kind of oil	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
	Pct.	Pct.	Pct.	Pct.
A0104	8	2	12	78
VDL-641	8	2	14	76
A104	8	2	12	78
2011-B	9	3	11	77
UC-1	6	2	81	11
Intermediate iodine value	7	2	46	45

Table 7 gives the contents of some of the fatty acids of representative safflower oils. Except for the high oleic oils and the oil with an intermediate iodine value, the amounts of oleic and linoleic acid vary very little.

Table 8.--High-oleic-acid safflower oils

Kind of oil	Induction period	Tocopherols	Oleic acid	Linoleic acid
	Hours	µg./g.	Pct.	Pct.
I.I.V.	722	506	46	45
143-173 Refined	1,274	494	79	15
71 C	1,648	583	79	15
71 B	1,694	448	78	14
71 A	1,794	575	80	13
UC-1	2,374	599	81	11

Table 8 is included to show the induction periods, tocopherol contents, and oleic and linoleic acid contents of high-oleic-acid safflower oils. These oils had long induction periods. It is interesting to note that the refined high-oleic-acid oil had a shorter induction period than does the unrefined oils. It was satisfying to us that this oil was refined elsewhere than in our laboratory.

Table 9.--Oxidation of 50-50 emulsion of safflower oil and water

Days at room temperature	Peroxide values	
	Oil emulsion	Oil
	meq./kg. of oil	meq./kg.
0	<1	<1.0
3	10	1.6
8	20	3.1
30	82	4.5
61	140	17.0
85	272	33.0
141	--	97.0

Table 9 shows the effect of emulsifying an oil upon the oxidative stability. Emulsions were prepared as follows. Oil containing a small amount of Tween 60 was placed in a blender and a weighed amount of ice added. The mixture was blended for a given time and placed in dark bottles. The peroxide value of the emulsion was compared with the nonemulsified oil placed in the same kind of bottle. Both bottles were shaken for a given period daily. Emulsifying the oil greatly increases the formation of peroxides.

HIGH-TEMPERATURE STABILITY OF SAFFLOWER OIL

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Professor Kemmerer (previous speaker) has spoken about antioxidants in safflower oil and its low-temperature stability. Lack of stability at ambient temperatures can be overcome by careful handling techniques--bottling under nitrogen, use of only stainless steel equipment to avoid contamination by trace metal ions, and by use of antioxidants, natural and synthetic, and other additives to inhibit oxidative deterioration.

With this problem under control, if not solved, what about the stability of vegetable oils, especially safflower oil, under conditions where oils and fats are used for cooking? During cooking, vegetable oils react to form polymeric materials which show up as lacquers and solid particles adhering to cooking vessels and food and more volatile components which are undesirable from the standpoint of flavor and odor. The nutritional value of both polymeric and volatile components is, at the very least, open to question (H. Kaunitz and others, J. Amer. Oil Chem. Assoc. 42: 770, 1965). Figure 1 shows some of the more visible results of heating safflower oil in the presence of air. The sample on the left is ordinary high-linoleic oil. That on the right is high-oleic oil, UC-1. Both samples were heated at 150°C. under air for 2 hours.

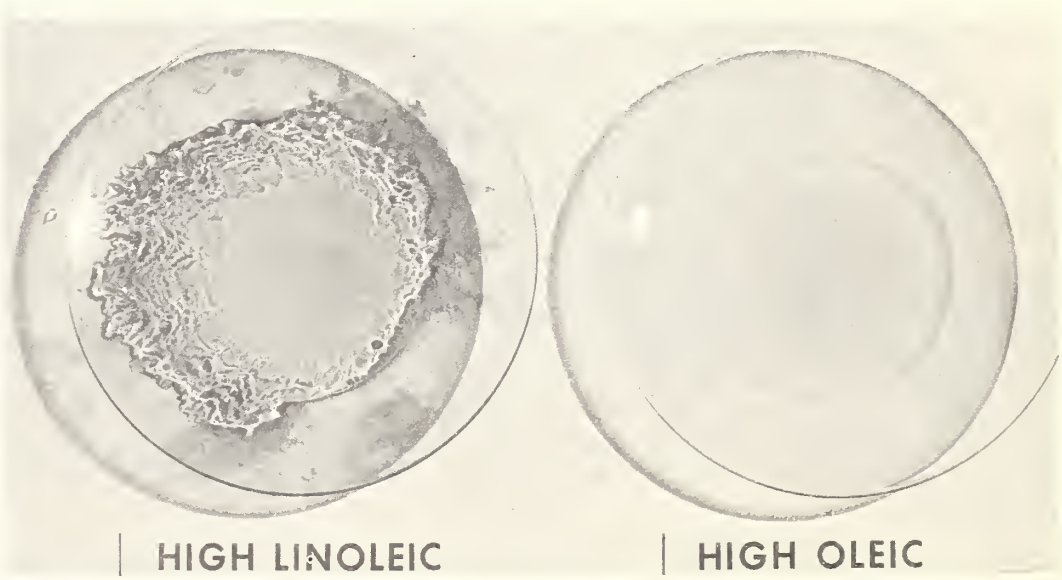

Figure 1. Comparative stabilities of two safflower oils at 150°C.

These high-temperature reactions keep unmodified safflower oil from entering the very large market of cooking fats and oils, a market which amounted to more than 2.5 billion pounds of oil in the United States alone in 1965. The question to us, then, is whether or not safflower oil or any other unmodified vegetable oil can obtain a substantial portion of the cooking oil market. To answer that question, we must know the answers to several other questions:

First, what is the nature of deterioration of fats at frying temperatures? Are the reactions involved purely oxidative or are other types of deterioration taking place? If the reactions are oxidative, are they similar to or different from the more well-defined reactions at low temperatures? When we determine what reactions are taking place, can we prevent degradation or at least slow it down to the extent that it is not harmful in frying operations? Next, can we do these things without destroying the nutritional qualities of the oil or without using quantities of additives which are unacceptable by Food and Drug Administration (FDA) standards? Finally, can the problem be solved in an economically feasible manner?

To answer all these questions, we have had to try a number of different approaches. First, it could be proved quickly that oxygen in the air was responsible for most, if not all, of the degeneration of the oil at frying temperatures. Heating safflower oil under nitrogen for 18 hours at 185°C. led to no polymer and almost no volatiles, while heating in air under the same conditions gave over 40 percent polymerized fatty acids plus a considerable amount of evil-smelling volatile products.

Answering questions about the kind of oxidation was more difficult. We have carried out oxidation of safflower oil at ambient temperatures and at high temperatures to see if we could tell if the reactions are different. We did this also with some synthetic chemical systems which are similar to the vulnerable spots in safflower oil. Figure 2 shows the preparation of one of these model compounds, cis,cis-6,9-octadecadiene (I). The methylene group between the two double bonds is the area particularly vulnerable to attack, both in linoleic acid and in the model hydrocarbon. Now we can examine the products from both low- and high-temperature oxidation of our model compound. These products should be similar if the oxidative reactions are similar. One cannot, by the way, prove the similarity by determining some simple value, such as peroxide number, because at ambient temperatures, the peroxide value may be above 1,000 while at frying temperatures it never gets higher than one or two meq./kg. If safflower oxidation proceeds by accepted methods, the two peroxides shown in figure 3 will be formed. These will cleave thermally at

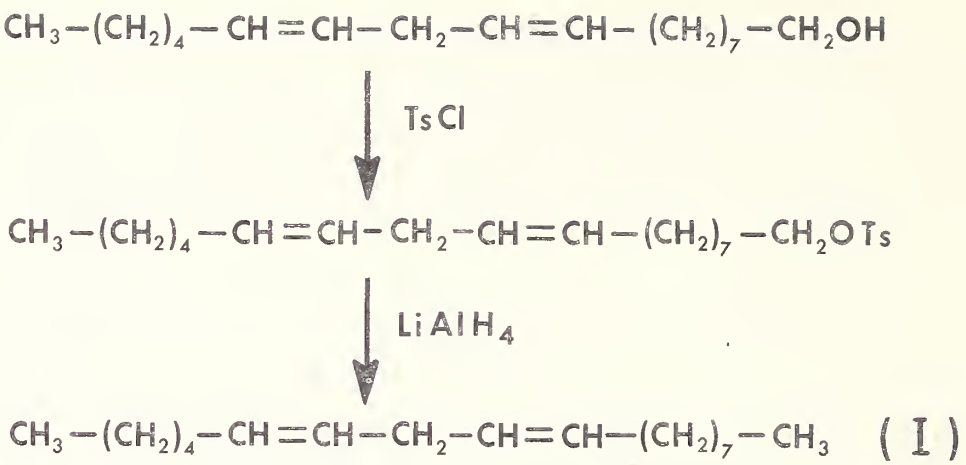

Figure 2. Model compound (cis, cis-6,9-octadecadiene).

the points indicated by the dotted lines. Now, when safflower or model systems are oxidized, we must analyze the products. The most difficult part of the problem is separation of the many components, which is best accomplished, in the case of the volatile compounds, by gas-liquid chromatography (GLC). Figure 4 shows a GLC trace of the volatile products from the model compound.

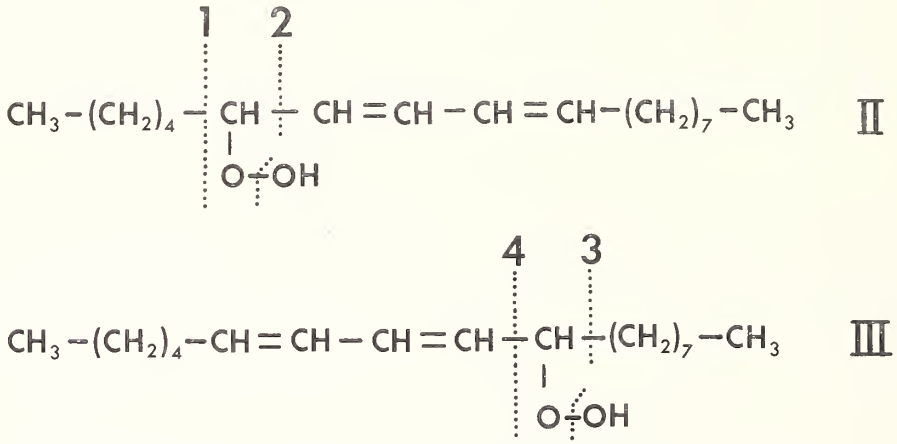

Figure 3. Two peroxides formed in the oxidation of safflower oil.

Once the oxidation products are separated, they must be identified. This is best accomplished by use of mass spectroscopy (MS). As each material came off the capillary GLC column, it was led into the ionization chamber of a time-of-flight mass spectrometer. Once tentative identifications were made, the products were compared with known compounds. By this means more than 30 compounds

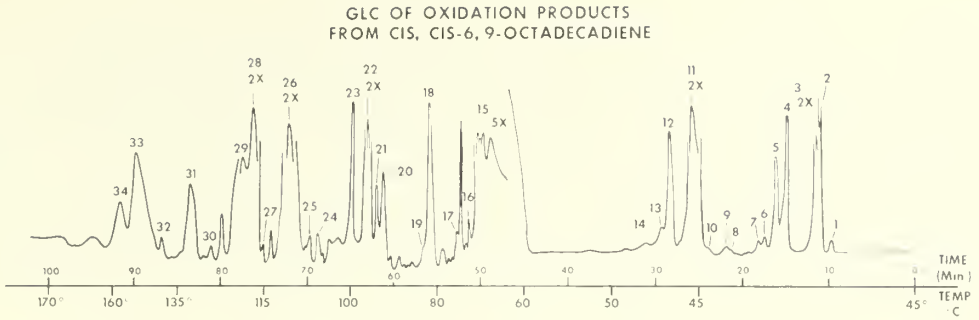

Figure 4. Analysis of model compound by gas-liquid chromatography.

were identified as oxidation products of the model compound. The products identified from the high-temperature of cis,cis-6,9-octadecadiene are listed below.

From Bond Scission at:

1	2	3	4
Pentane (3)	Hexanal (15)	Octane (15)	Nonanal (33)
2-Pentanone (10)		2-Octanone (28)	
Pentanal (11)		Octanal (28)	

From Subsequent or More Complex Reactions:

Acetaldehyde (1)	2-Heptanone (20)	Octyl formate (34)	Hexane (5)
Acrolein (2)	3-Hexene-1-ol (15)	Furan (3)	Methylcyclopentane (7)
Propanal (2)	Propyl formate (4)	Methylfuran (5)	
Butanal (4)	Butyl formate (13)	Methyltetrahydrofuran (9)	1-Hexene (10)
2-Hexenal (18)	Pentyl formate (16)		
Heptanal (22)	Hexyl formate (19)	Ethylfuran (11)	Heptane (12)
2-Heptenal (26)	Heptyl formate (30)	Butylfuran (21)	Nonane (23)
		Hexylfuran (32)	

The underlined compounds are the ones found at high but not at low temperature. The number of these is somewhat misleading, because actually the bulk of the products are those resulting directly or almost directly from bond scission at the four points shown in figure 3. Hence, our conclusion is that the oxidative reactions at high temperature are similar to those at ambient temperature. This conclusion leads us to the belief that we can control oxidation at high temperature by means found to be successful for preservation of oils during storage, especially by use of antioxidants.

Some preliminary work has been done to try this approach. High-linoleic oil has been heated at 185°C. with varying amounts of antioxidants. The amount of polymer formed in a given period

of time was used to determine the effectiveness of the antioxidant. So far, only synthetic antioxidants such as butylated hydroxy toluene (BHT) and propyl gallate have been used. At concentrations allowable by the FDA (0.01 percent), the antioxidants showed no inhibitory effect at all. However, when the concentration of BHT or propyl gallate was increased to 1 percent in the oil, an inhibitory effect was shown. Apparently, what we need is an antioxidant so effective that it can be used at low concentrations or one so cheap and so nontoxic that it may make up 1 to 2 percent of commercial oils. The second solution is really unlikely--the first is possible but we do not have good leads toward the types of compounds necessary. Certainly, less volatile antioxidants than current commercial ones would be a help. Lauryl gallate instead of propyl gallate may be an improvement, but not one of two to three orders of magnitude, which is necessary for good, high-temperature performance.

If ordinary safflower oil is partially hydrogenated so that about 16 percent of the double bonds are saturated, the amount of inhibitor necessary can be reduced to about one-tenth that needed for stabilizing the pure oil. The disadvantage is that the double bonds are isomerized and a considerable part of the oil is solid at room temperature.

The partial hydrogenation of safflower has already been done for us in a most effective way by Professor Knowles. His UC-1 safflower essentially reverses the oleic-linoleic ratio of safflower as shown in table 1. Here is a high-oleic safflower oil which has

Table 1.--Safflower oil compositions

Fatty acid	High linoleic	High oleic
	Pct.	Pct.
Palmitic	6.0 to 6.8	5.4
Stearic	2.1 to 2.9	1.7
Oleic	9.8 to 12.7	79.4
Linoleic	77.5 to 81.0	12.0
Others	0.2 to 0.8	1.5

none of the disadvantages of a hydrogenated oil. It is liquid at refrigerator temperatures. We have shown it to be comparable in stability to hydrogenated cottonseed oil already used in commercial deep-fat frying. We have extracted and refined a considerable quantity of this oil. Some of it has been sampled to industry. We have, in cooperation with our Vegetable Laboratory, done some potato chip frying in the oil. Only preliminary smell-panel results are available from these frying experiments. The panel preferred the chips fried in safflower oil over those fried in commercial chip oil during the early stages of storage up to about 5 weeks. No rancidity had developed at that time.

In summary, then, we want to stabilize safflower oil so that it can be used for cooking. We have established that high-temperature degradation is oxidative and that the reactions are similar in nature, if not precisely the same, as those of low-temperature oxidation. We have a few leads toward stabilizing high-linoleic safflower oil but are a long way from doing it in a practical way. Finally, if the high-oleic safflower continues to look as good as it does now, maybe a good vegetable oil for the cooking oil market is already here.

THE CHANGING SCENE OF FATS AND OILS

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I shall discuss the food-fat-and-oil ball game in which safflower oil is playing an increasingly important part. The development of a new type of safflower oil, the high-oleic variety (UC-1), increases the potential for safflower in the total picture. No attempt will be made to speculate on which position UC-1 will play, or even if it will become a regular player. Such a determination depends upon factors not yet fully determined.

An appraisal of the whole ball game will have benefits beyond our immediate interest here. Those directly concerned with research, production, and marketing phases of an industry can frequently benefit by stepping backwards and taking a broader look. They can view the situation as a forest instead of trees. Such a look may reveal changes and trends that are not readily apparent or even suspected by some. My purpose is to take such a look at the uses and origins of our food fats and oils. This appraisal will involve the fourth dimension, for we shall consider changes through time as well as the situation at present. By considering changes and trends of the past, we hope to sharpen our perspective of the future.

Of particular interest and perhaps concern to many are the possible effects on future supplies and demands if the strong trends of the past persist. A continuation of these trends would result in dislocations and adjustments so drastic as to cause virtual disappearance of some sources and outlets of food fats and oils. Obviously, such trends cannot continue; the problem becomes one of determining where the endpoint will be--higher, at present levels, lower, or in between.

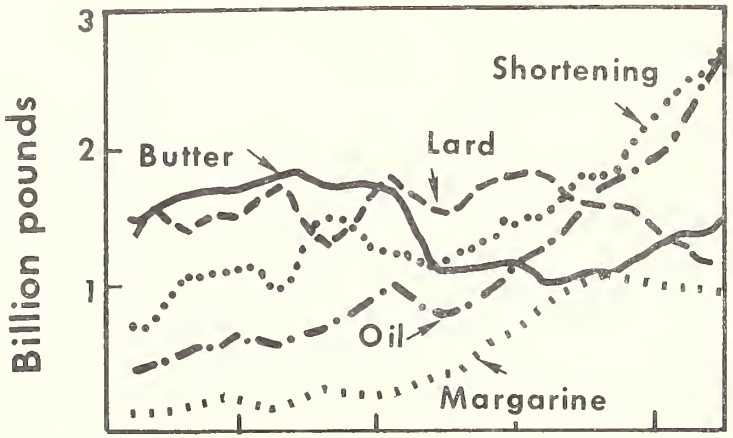

Figure 1. Utilization of fats and oils.

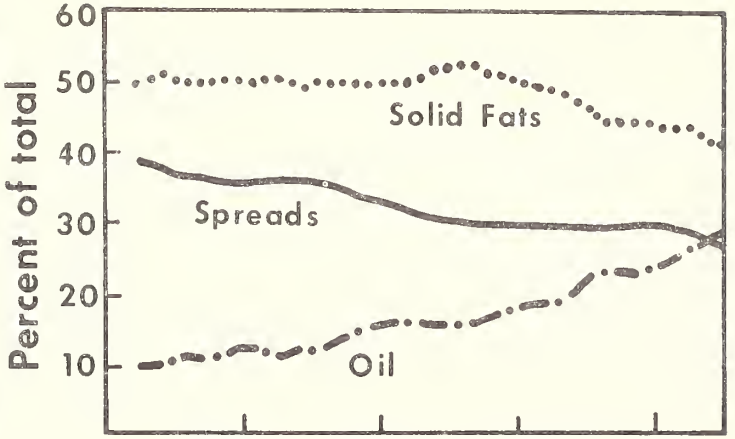

Figure 3. Relative importance of product groups.

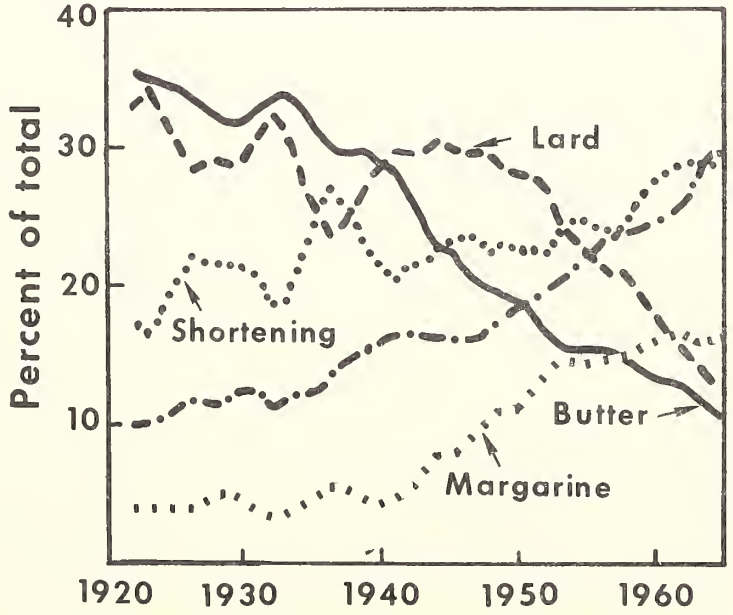

Figure 2. Relative importance of products.

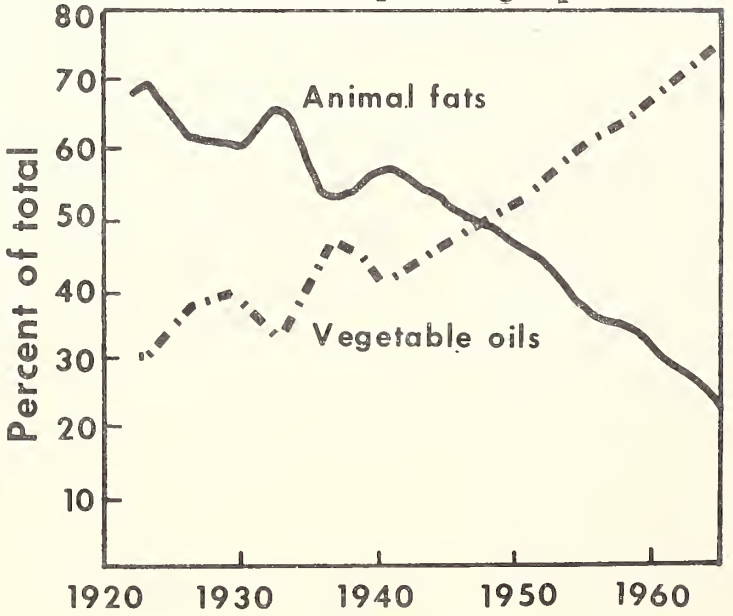

Figure 4. Primary sources.

The period of references extends from 1920 to 2000 A.D. Only food fats and oils are considered. In most cases, data presented are 3-year moving averages to minimize year-to-year fluctuations. Only fat content of the product is considered. Thus, butter and margarine fat weights are about 80 percent of product weights. In charts showing products, reference to lard includes only lard sold as such. Lard used in margarine and shortening is included under those respective headings. In charts showing sources of fats and oils, figures for lard are for the total supply.

The main source of data is Statistical Bulletin No. 376, "U.S. Fats and Oils Statistics, 1909-65," published by the U.S. Department of Agriculture, Economic Research Service, August 1966. Assumptions about future trends are my own, based upon available information.

Our first look backwards is shown in figure 1. Total consumption of fats and oils increased from 4.3 billion pounds in 1921-23 to 9.2 billion pounds in 1964-66, a 114 percent increase. Population grew from 110 million to nearly 200 million, an 80 percent gain; hence per capita consumption increased. In spite of population gains, use of butter and lard (as such) declined while consumption of margarine, shortening, and oil increased greatly.

To remove the effect of population growth, figure 2 shows the proportion of total fats and oils going into each product group. The changing relationships that have been going on for 45 years are very much in evidence. The relative decline of butter and lard and the growth of oil and margarine are even more obvious.

Margarine is a substitute for butter, and lard and shortening are substitutes for each other. The increase in margarine did not totally offset the decline in butter; and shortening fell short of making up for the decline in lard. So, while butter and margarine were battling it out on first base, and lard and shortening were squaring off on second, oils stole home from third (figure 3). Both spreads and solid fats lost ground while oil increased its importance by threefold. In any effort to assess future changes in product use, a knowledge of why oil has become so important is necessary. Was it improved technology that made the production of stabilized oils possible? Was it the desire for a more convenient form of fat or oil? Do oils have better use properties such as flavor, color, appearance, and handling? Has the recent interest in polyunsaturates been a factor, and will it be a factor in the future? Some nutritionists believe substitution of polyunsaturates for the more saturated fats results in decreased cholesterol in the blood (see report by Kinsell and others, page 48).

Table 1.--Consumption of food fats and oils, 1963-65 average

Item	Approx. total Million pounds	Per capita pounds	Percent of total
All fats and oils	9,200	47.3	100.0
Spreads (fat content)	2,600	13.3	28.1
Butter	1,070	5.5	11.6
Margarine	1,530	7.8	16.5
Cooking fats	3,900	20.1	42.5
Lard (direct use)	1,240	6.4	13.5
Shortening	2,660	13.7	29.0
Other edible fats and oils	2,700	13.9	29.4
Mayonnaise and salad dressings	760	3.9	8.2
Potato chips	330	1.7	3.6
Frozen french fries	70	0.34	0.7
Mellorine	20	0.1	0.2
Other	1,520	7.9	16.7

Source: From data on per capita consumption, In "U.S. Fats and Oils Statistics--1909-65" (table 137), U.S. Dept. Agr. Stat. Bul. No. 376, 1966.

Table 2.--Use of fats and oils in manufacture, 1963-65 average

Item	Marga-rine	Short-ening	Total	Other (mainly oils)					
				Salad dressings	Potato chips	Frozen french fries	Mello-rine	Other oils	Total
	Million pounds								
Lard	79	499	578	--	--	--	--	--	--
Edible tallow	15	410	475	--	--	--	--	--	--
Subtotal	94	909	1,003	--	--	--	--	--	--
Coconut oil	5	19	24	--	--	--	--	--	--
Corn oil	149	6	396	13	--	--		228	241
Cottonseed oil	106	369	1,653	162	234	--	--	766	1,178
Peanut oil	6	4	63	--	--	--	16	53	53
Safflower oil	13	10	41	--	--	--		18	18
Soybean oil	1,100	1,363	4,158	582	--	--		1,113	1,695
Other oils	--	--	112	--	78	--	3	--	78
Miscellaneous	22	9	65	--	--	65	--	--	65
Subtotal	1,401	1,780	6,512	757	312	65	19	2,178	3,331
Total of items listed	1,495	2,689	7,515	757	312	65	19	2,178	3,331
Total from table 1	1,530	2,660	6,890	760	330	70	20	1,520	2,700

Source: From data in U.S. Dept. Agr. Stat. Bul. No. 376 (tables 141, 142, 143, 144, 145, and 146), 1966.

Does this growth in the use of oils mean our diet is significantly improving and our health better?

In the first half of the 45-year period, increase in oil use occurred at the expense of butter, whereas in the last half, the gain was made at the expense of solid fats. Is this significant? Did oil first replace spreads for cooking and later solid fats?

Figure 4 shows the derivation of fats and oils by primary source--animal and vegetable. In 40 years, their relative position has about reversed. A continuation of these practically straight-line trends into the future would have vegetable oils accounting for 100 percent of the supplies by the year 2000 A.D. Because this obviously will not happen, these trend lines must soon take a slightly different course.

A closer look at current uses of fats and oils is given in tables 1 and 2. Some duplication of uses is obvious in table 2 but data are not available to eliminate it. Butter and lard as such are not included in table 2. The wide adaptability of vegetable oils, in contrast to animal fats, is apparent. The two largest sources of oil (soybean and cottonseed) are used in oils, shortening, and margarine, in that order of importance. Even soybean oil, having greater color and flavor problems, is used in greatest quantity in liquid form. Cottonseed oil is preferred in the manufacture of potato chips. Other preferences exist but are not reflected in the figures.

The fast growing processed potato market took 375 million pounds of oil in 1963-65; and in 1966 the quantity used was close to 500 million pounds. Some clarification of these data is needed. While the products are called oils, they are probably hydrogenated to solid or semisolid form for these manufacturing outlets. Estimates of the quantities of oil used in the manufacture of potato products are based upon the following assumptions:

	Potato chips	Frozen french fries
Pounds of potatoes to make one pound of produce	4	2.5
Percentage of oil in product	40	8
Type of oil used, percent	75 percent cottonseed oil--remainder mostly corn oil, but also soybean, peanut, and lard.	Not given

The production of potato chips has increased more than two fold in the past 10 years and that of frozen potatoes (mainly French fries), by sevenfold. These trends are expected to continue. Oils used in mellorine are 85 percent cottonseed and soybean, but also include coconut, corn, and peanut oils and meat fats.

Looking ahead. The Secretary of Agriculture has given several talks recently about Agriculture--2000 A.D. The same target date is used herein. We shall now look ahead to see where trends are leading and to consider the probable availability of supplies to meet the needs. Estimates of supplies and requirements by the year 2000 are likely to fall between the quantities indicated by present trends (or modified if the projection is clearly unlikely) and the quantities indicated if present percentages of total needs are maintained.

The first step in looking ahead is to estimate probable total requirement, which is simply the product of population multiplied by per capita use. Estimates of population by 2000 A.D. vary, but seem to center around a total of 300 million people. This represents a growth rate of about 1.25 percent annually.

A continuation of the trend in per capita consumption of the past 15 plus years would put the figure at around 55 pounds by 2000 A.D. If we use only the past 10 years, the figure is around 52.5 pounds. Present per capita consumption is about 48 pounds. The middle figure will be used, only because it is the middle. It may prove high, if current interest in nutrition and the relation of fats to health results in any changes in diets. The estimate may be low if the past trends prevail.

A population of 300 million consuming 52.5 pounds of fats and oils per capita will require a total supply of 15.75 billion pounds in 2000 A.D. This is a gain of 70 percent from the present use of just over 9 billion pounds. Where will this huge quantity come from?

Figure 7 shows the percentages of the total that each of the major sources supplied over the past 45 years and approximations of trends into the future. Butter, lard, and cottonseed oil declined in importance. Coconut and corn oils and beef tallow increased. Soybean oil skyrocketed. If these trends were to continue, in the not too distant future soybean oil would be the sole source of our food fats and oils. Butter would disappear. Neither trend is likely or even possible, so adjustments are made. The trend for butter is arbitrarily rounded out to 5 percent. The trend line for soybean oil leaves the chart, but is also arbitrarily set at 50 percent by 2000 A.D., allowing for the indicated importance of other sources of fats and oils.

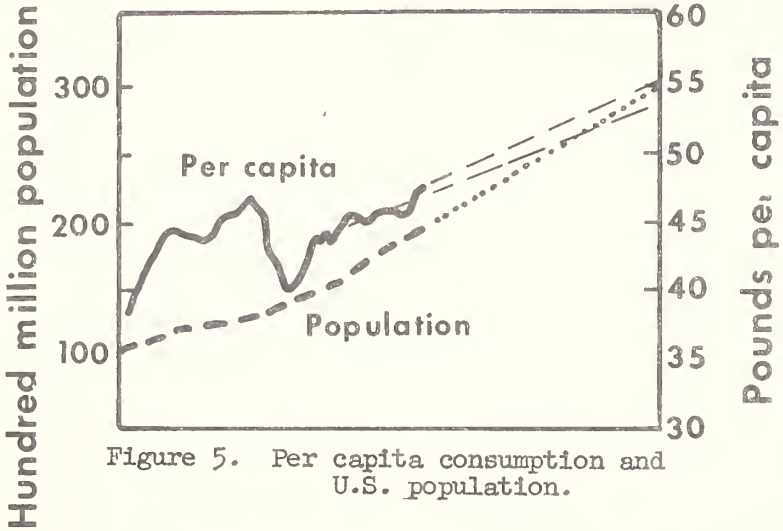

Figure 5. Per capita consumption and U.S. population.

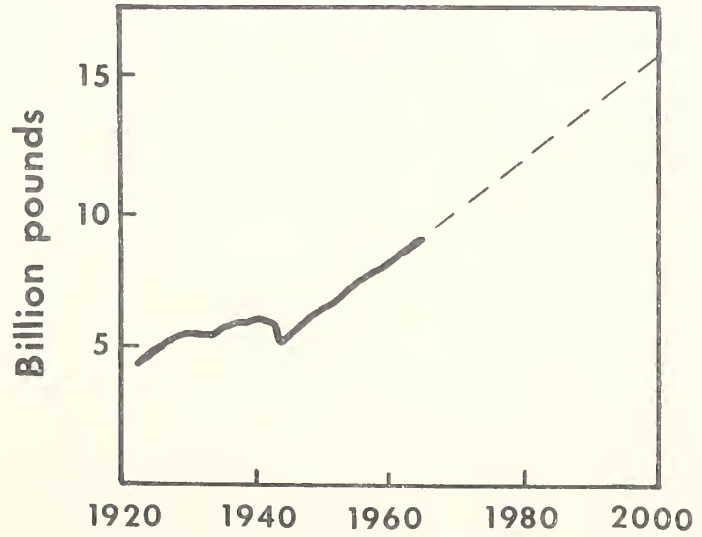

Figure 6. Total consumption.

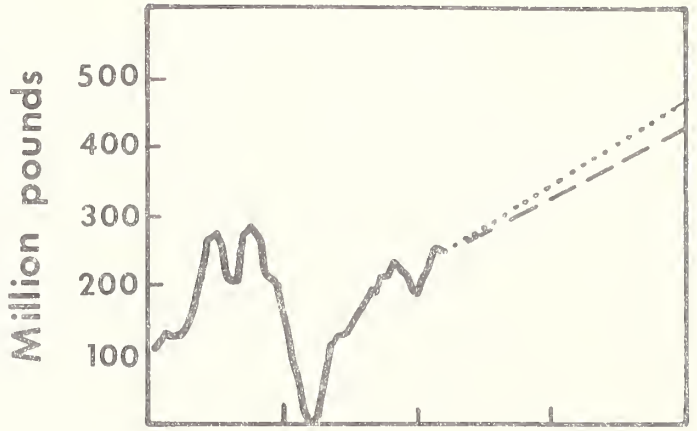

Figure 8. Coconut oil.

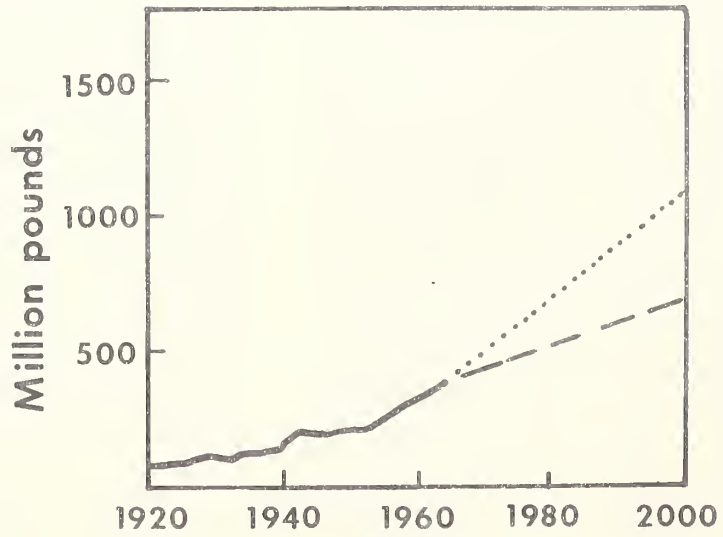

Figure 9. Corn oil.

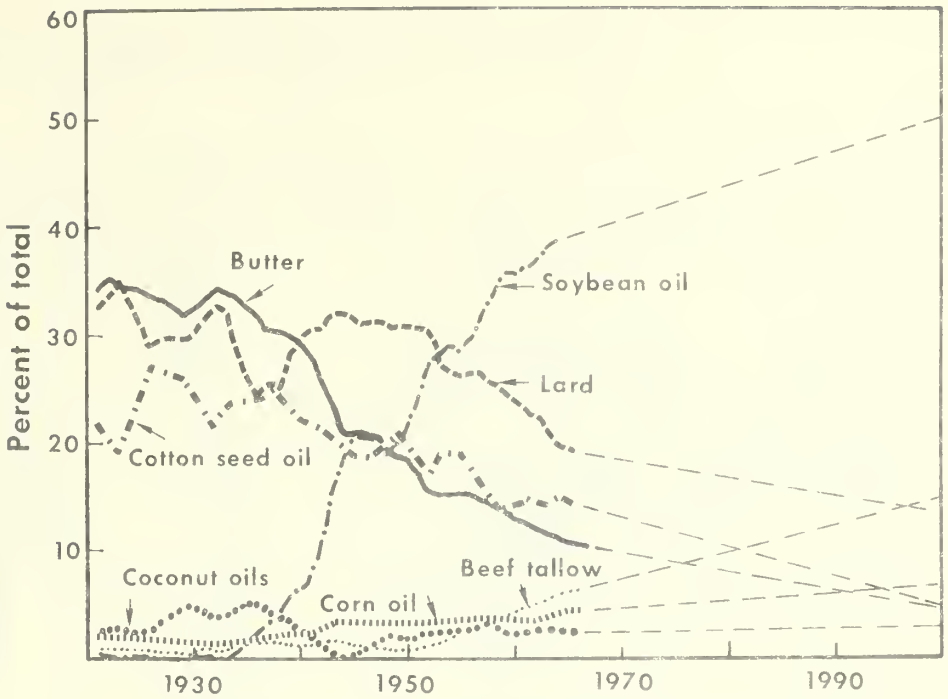

Figure 7. Relative importance of major sources of food fats and oils.

In the following graphs, projections to 2000 A.D. for each major source of supply are expressed on two bases: (1) Assumption that present percentage of total supply is maintained. The increase to 2000 A.D. will be about 70 percent in each case, in line with total requirements. This trend is shown as a dashed line. (2) Assumption that present trends (adjusted as already mentioned) will continue. In some cases, requirements will be significantly above, not only present supplies, but above the average increase of 70 percent. This trend is shown by a line made with small circles. Each major source of supply is now considered individually.

The importance of coconut oil (figure 8) was interrupted by World War II. Present food usage is around 250 million pounds. Projections to 2000 A.D., depending upon assumptions discussed above, suggest a total requirement somewhere between 420 and 470 million. Our current use of coconut oil for other purposes is about double the food use. Inasmuch as coconut oil is imported, continued supplies will depend upon many factors outside the food fat and oil market, political considerations being among the most important.

Next is corn oil, which has had a steady growth not only in total production but also in relative importance (figure 9). Practically no corn oil is exported. Projections to 2000 A.D. indicate corn oil requirements between 675 million and 1.1 billion

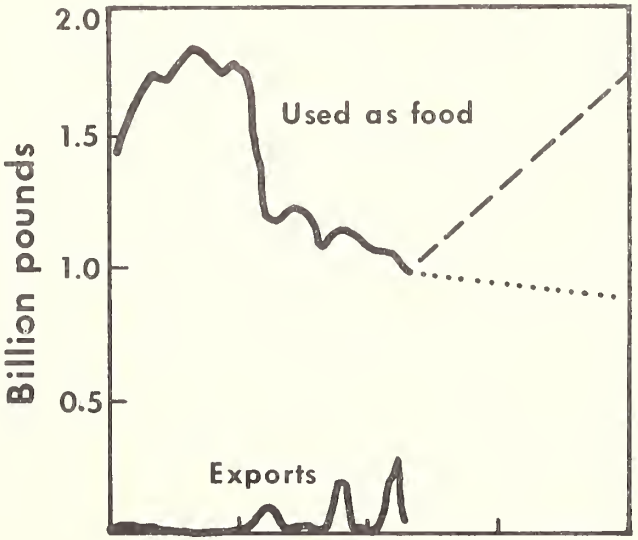

Figure 10. Butter.

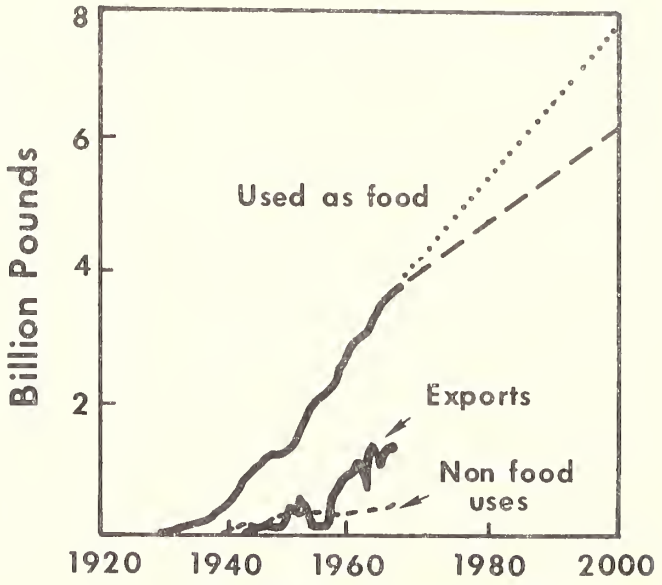

Figure 12. Soybean oil.

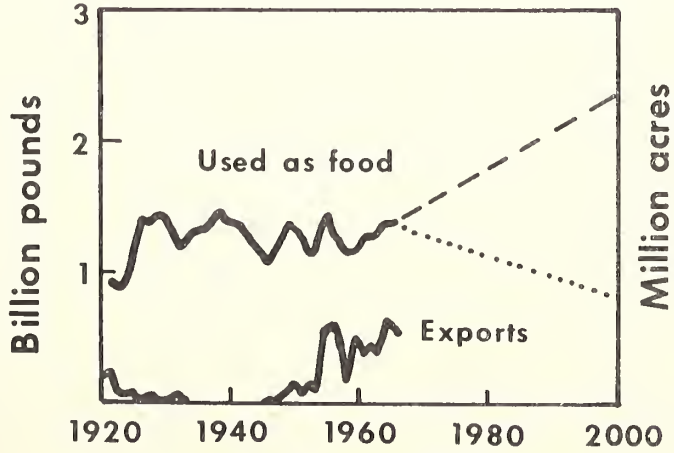

Figure 11. Cottonseed oil.

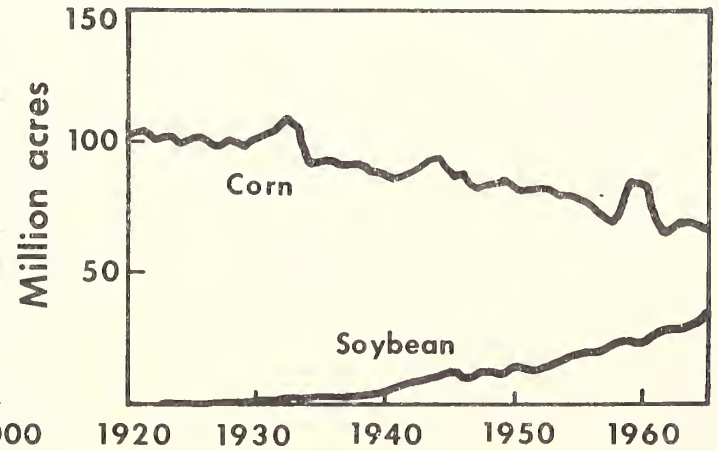

Figure 13. Acreages.

pounds compared with 400 million in the midsixties. The top estimate reflects an increase of 180 percent.

Corn oil is a byproduct of the cornstarch industry. Consequently, the supply of corn oil is determined by factors largely outside the fat and oil industry. It is unlikely that oil could become the main product and starch the byproduct unless new types of corn extremely high in oil are developed and found commercially feasible.

The demand for cornstarch will be affected by at least four factors: (1) Population increase of 50 percent to 2000 A.D. (2) Resins are capturing a share of the fiberboard sizing market, a large outlet at present for cornstarch. (3) Increased use of wash-and-wear garments results in decreased use of starch in laundering. (4) Technological developments not yet determined. Unless new uses are developed for cornstarch, one might predict that the supply of corn oil may not reach its projected top potential--barring unforeseen technological gains.

World War II brought about a major decline in butter production (figure 10). No significant recovery followed, and butter production declined slowly over the past 20 years to the lowest point in modern history. Perhaps a change in the way milk is priced to give butterfat a lower value could result in increased butter use. It appears fairly certain, however, that butter will decline in relative importance and perhaps even in total quantity as shown in figure 10. The requirements in 2000 A.D. could lie between 850 million and 1.7 billion pounds, compared with about 1 billion at present. Exports of butter are relatively minor.

Many factors outside the fat and oil industry affect the demand for butter. Butterfat is sold as a component of whole milk, cheese, ice cream, and evaporated milk, the production of which has increased as sale of butter declined. Demand for butterfat in these products versus the demand for butter as such (which is a function of butter prices and butter desirability) will help determine the long-run trend in butter production. New products having the characteristics of butter but made from other sources will also affect butter supplies and demand. Such products include in addition to margarine, imitation ice cream, coffee whiteners, and whips.

Cottonseed oil (figure 11), like butter and lard, declined in relative importance. Exports amount to about a third of domestic use and could be used to augment supplies if economics dictate. Present use of cottonseed oil, just under 1.5 billion pounds, could increase to nearly 2.4 billion pounds or decrease to 800 million pounds, depending upon assumptions used to project demand to 2000 A.D.

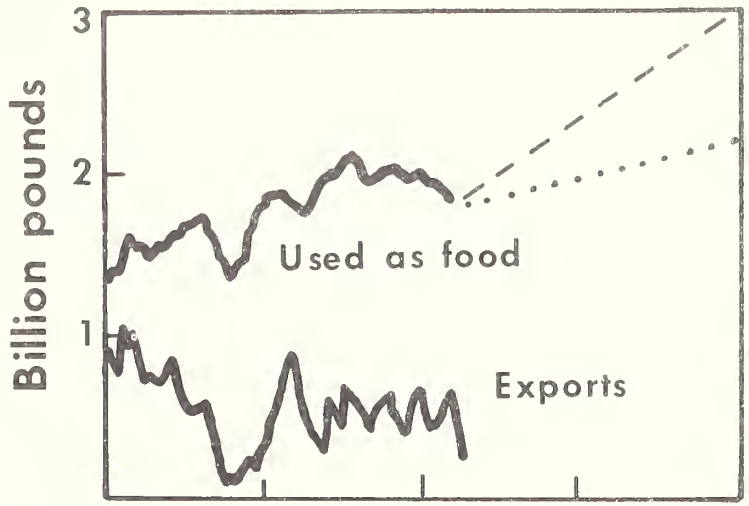

Figure 14. Lard.

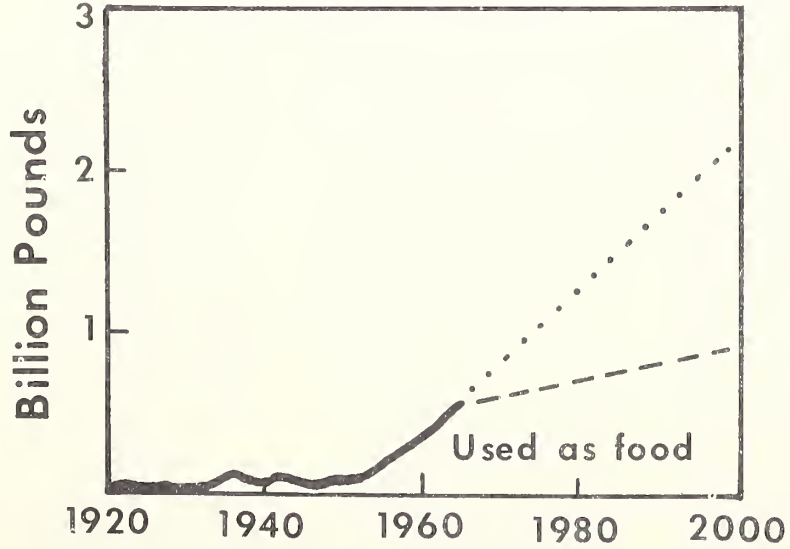

Figure 15. Edible tallow.

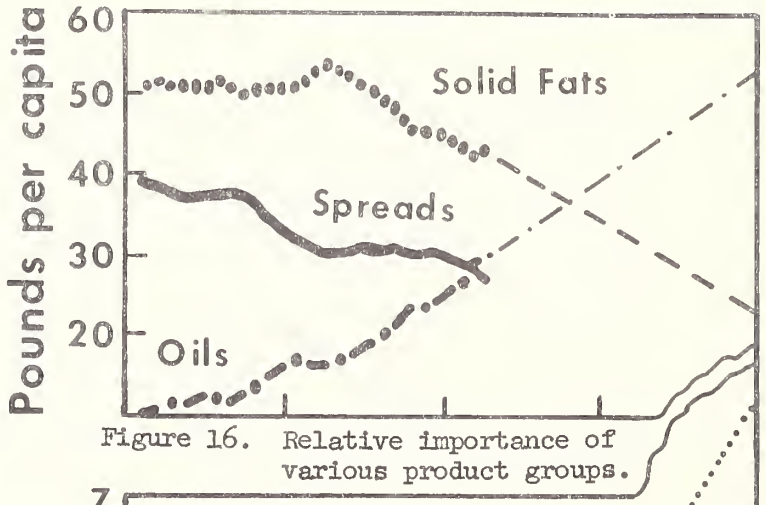

Figure 16. Relative importance of various product groups.

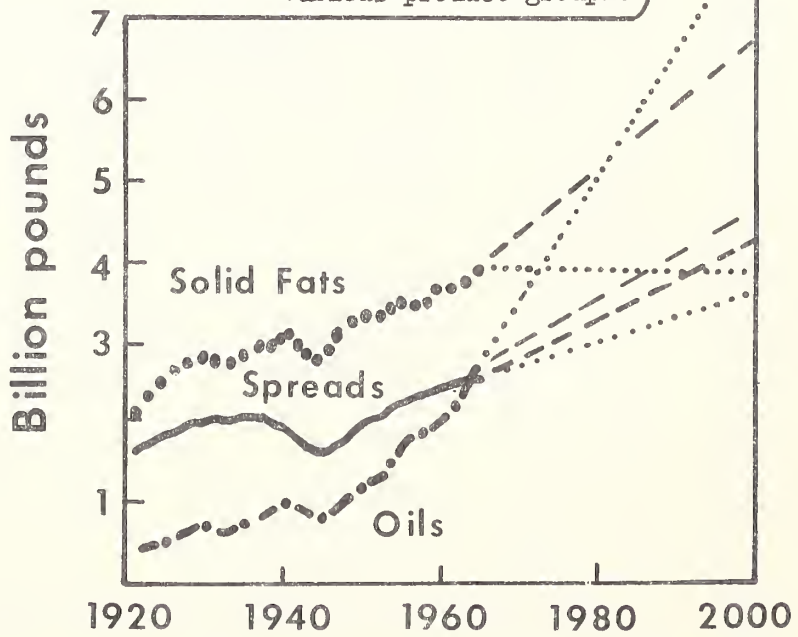

Figure 17. Requirements of various product groups.

The future of cottonseed oil is uncertain, tied as it is to the production of cotton. It is unlikely that cotton production will increase much under existing conditions and in competition with synthetic fibers. Practically all cottonseed is crushed for oil, and little gain is possible there. Only the cottonseed oil exported could become a sure addition to domestic supplies if conditions warrant.

Current interest in polyunsaturated oils favors increased use of both corn and cottonseed oils. Both are byproducts, however, and their supply depends upon the demand for the primary products.

Soybean oil has come from virtually nowhere to the dominant position in the fats and oils supply picture (figure 12). If soybean oil increases from the present 39 percent of total fats and oils to only 50 percent by 2000 A.D., requirements will become a staggering 8 billion pounds. Today the supply is less than half that. If soybean oil maintains only its present relative importance, the demand will amount to over 6 billion pounds. Exports of soybean oil equivalent are about one-quarter of the total supply and have been increasing.

To supply the high estimate requires a virtual doubling of soybean production and soybean acreage. Soybeans are now grown on over 30 million acres. One can rightfully question the ability of the country to double this acreage, particularly in view of total world food needs and the possibility of our trying to supply them.

Soybean oil, while not considered exactly a byproduct, is a coproduct of soybean meal. For every ton of soybean oil produced, the economy must absorb 4 tons of soybean meal. In 1966, soybean cake and meal production amounted to 13 million tons of which nearly 3 million were exported. The 10 million tons used for feed was 80 percent of all oilseed meals fed, but only 6 percent of all concentrates fed--including grains. The desirability of soybean meal as a feed, the small percentage it now accounts for in total concentrate feed supplies, the increasing per capita use of most livestock products, and the increasing exports of soybean meal suggest that there should be little trouble in the future in disposing of significant additional quantities of meal.

Any question of soybean oil supply must be a matter of available acreage. During a period when grain acreage was under governmental controls, soybean acreage increased greatly.

The obvious inverse relationship between corn acreage and soybean acreage is shown in figure 13. One question for the future is whether or not increased grain acreage would result in less soybean acreage. Under present conditions, gross returns

from corn are greater in some important growing areas than from soybeans. The following data show the relationship in Illinois, the major producer of soybeans, for 1965:

	Corn	Soybeans
Average yield per acre----------bushels----	92	29
Average price per bushel----------	$1.07	$2.40
Gross return per acre----------	$98.50	$70.00

I have heard that there seems to be little possibility for substantially increasing soybean yields, but higher corn yields are certain. Some plots have yielded over 300 bushels per acre.

If the experience of the past, the inverse correlation, works exactly in reverse (that is if a relaxation of restrictions on grain acreage results in a ready diversion of acreage from soybeans to corn) then the net result could mean lower corn prices and higher soybean prices so that soybeans could compete better for acreage. Obviously, technology will have an important role in the outcome.

Soybean acreage has been expanding significantly in the South in areas where cotton acreage has been restricted. In fact, soybeans have become so attractive in these areas that they are being grown on land not previously in cotton. Gross returns for soybeans are less than for cotton, but costs are also less. Continued restrictions on cotton acreage should continue to favor increased planting of soybeans in the South.

Lard, like cottonseed oil, has declined in relative importance but has increased somewhat in total quantity used as food (figure 14). The total demand by 2000 A.D. could lie between 2.2 and 3 billion pounds--both above the present 1.8-billion-pound food use. Exports have trended downward and amount to about one-fifth of the total supply.

Lard is a byproduct of pork slaughter, and per capita consumption of pork has been declining. It does not appear likely that lard will be able to maintain its present relative importance in the total food fats and oils picture. Production of lard, however, will likely increase, because growth in population appears to be at a more rapid rate than the decline in pork consumption.

A surprising gainer has been edible beef tallow (figure 15). Until 1950, it was an almost insignificant item. In 15 years, the quantity used rose from less than 100 million pounds to 500 million. This rate of growth will probably not be maintained, but the total quantity used as food could continue substantially upward. The quantity predicted in 2000 A.D. could range between 900 million

pounds and 2.2 billion pounds. Exports are minor. The production of edible beef tallow in 1965 of just over 500 million pounds compares with the production of inedible beef tallow and greases of over 4 billion pounds. About half the inedible tallow is exported. The recent growth of edible in relation to inedible tallow suggests that further gains could be made in the supply of this food fat even though total beef slaughter were to remain constant. Knowledge of the factors that determine the split in these products, however, is necessary to permit a meaningful assessment.

Edible tallow is a byproduct of beef slaughter, which is one of the few items we have found in which the future supply appears headed strongly upward. Population, incomes, and per capita beef consumption are all increasing. Perhaps an important consideration concerns the quality factors of beef tallow in relation to the quality factors needed in fat and oil products. Just as technology has made possible stable food oils out of raw materials previously considered deficient in some respects, technology may be expected to similarly expand beef tallow utilization.

New sources. This completes the review of trends and prospects for the major sources of food fats and oils. We must always recognize, however, that other sources may rise to great importance just as soybean oil did after the midthirties.

Sunflower seed is important in other countries, particularly in U.S.S.R. Sunflower seed oil production in the world about equals that of cottonseed oil--around 2.5 billion pounds. Production of sunflower seed oil has doubled from the 1955-59 average. A. R. Baldwin of Cargill, Inc., reported at the American Oil Chemists' Society's 50th annual meeting in New Orleans last May that the Russians, by judicious selection and crossbreeding, have developed a high-yielding sunflower that produces seeds containing up to 50 percent oil. The normal oil content has been around 25 percent, but current seed of Russian plants has around 43 percent.

Sunflower does well in cooler climates, such as the northern areas of our Central Plains. Thus it would compete more with wheat than with corn or soybeans. About 75,000 acres of sunflower are reported planted this year in the United States. Prior production has been nil. The fact that sunflower is possible and that it can be best grown on acreage that is not competitive with soybeans, cottonseed, corn, or safflower suggests that the seed oil may have an important place in the market in the future.

Safflower oil, a newcomer that has attained commercial importance, should continue to expand in the food field. Safflower grows best in a warm dry climate, such as the area west of the 100th

meridian. Thus vast areas of the Intermountain and Pacific Coast States are adapted to safflower. The new high-oleic variety gives safflower a product to meet additional outlets--as a stable liquid oil well-suited to deep-fat frying and as an industrial raw material, particularly for the extraction of oleic acid. The high degree of unsaturation of the varieties now produced meets requirements of a market concerned with the health aspects of fats and oils. New varieties with high oil content and soft small hulls and also improved techniques of processing the meal for feed or food should further improve safflower's potential in the total food fat and oil market.

Figure 16 attempts to project the relative importance of the three general classes of products to 2000 A.D. A continuation of present trends would have oil accounting for over 50 percent of the total requirement. On the basis of these trends and on a continuation of present relative importance, total indicated quantities are shown in figure 17. The need for oils by the year 2000 A.D. could range from 4.75 billion pounds to 8.25 billion pounds, compared with less than 3 billion now. The requirement for solid fats may be between 3.8 billion pounds and 6.75 billion pounds compared with the current nearly 4 billion pounds. And spreads could range from 3.6 billion to 4.5 billion pounds compared with 2.5 billion at present.

Summary. Each of us will interpret these data in a different way. Some will project different data based upon other assumptions. Here is a summary of what I believe the data show.

1. We have seen a rise in per capita use of fats and oils, and available statistics show the trend continuing. No turndown has yet manifested itself.

2. The relative importance of spreads and solid fats has declined and that of oils has increased. Those trends seem fairly sure to continue.

3. Aside from butter, lard, and coconut oil, there seems to be great interchangeability among oils in end use, but there are some exceptions on the basis of preference.

4. Total food use of fats and oils will increase 70 percent by the year 2000 A.D.

5. There is considerable variability among the fats and oils in their apparent ability to meet the demands of 2000.

6. Supplies of corn and cottonseed oils, lard, and beef tallow are not related directly to fat and oil needs. Of these four sources, only beef fat appears fully assured of substantial growth.

7. The major single source of oil is soybeans--and the future for that crop is not entirely certain. (a) It competes for acreage with crops now under price support and acreage restrictions. (b) World food needs and our willingness to supply them will have an important effect on acreage availability.

8. Of the major food oils, only coconut is imported in quantity. The future could well bring more and other imports.

9. Safflower and sunflower seed oils can be expected to become increasingly important in the total picture.

10. But technological advances yet to come, some not even suspected at present, can surely change trends, projections, and fears. It is well to look at total picture in the light of past and present developments. Those concerned with technology are then enabled to see where the industry appears headed and can better help in either furthering or redirecting the course.

When the long-term needs for increased fat and oil supplies are considered, the trends recognized, and the probable limitations on supplies admitted, we must venture the opinion that there is an important place not only for safflower oil but for other oils of desirable nutritional and physical properties.

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SAFFLOWER MEAL IN POULTRY RATIONS

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My subject is the use of partially decorticated safflower meal as a protein source for broiler rations. For obvious reasons, its use is most interesting in areas where safflower is produced. California is one of these areas; here, we have a broiler industry of over 220 million pounds per year. This requires over 80,000 tons of protein supplement, which includes such ingredients as soybean meal, cottonseed meal, fish meal, meat meal, and probably very little safflower meal at present.

Since a considerable amount of safflower meal is produced in California, we investigated its use in broiler rations. The safflower meal I am talking about contains 42 to 45 percent protein and 12 to 16 percent fiber. It has two main problems for broilers. It is low in the essential amino acid, lysine, and it has a relatively low metabolizable energy. Its low lysine content is demonstrated by the chick lysine dose-response curve in figure 1. However, you will note that when adequate lysine is added to the safflower ration, chick growth is superior to that from the corn-soy ration.

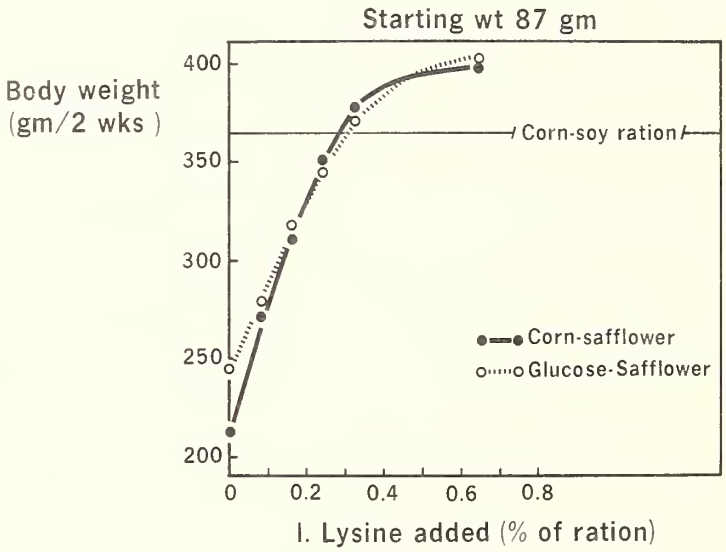

Figure 1. Growth response to added lysine.

The rations used here and in other experiments I will discuss are 22 percent protein practical-type rations. They are similar to commercial rations except that they contain extra added vitamins and a relatively high level of vegetable oil. The soy and the safflower

meals constitute about 32 to 41 percent of their rations, depending on the protein content of the individual ingredients.

Over a period of 3 years we conducted nine experiments comparing lysine-supplemented safflower rations with soy rations. Both rations contained 1.1 to 1.2 percent lysine and were calculated to be complete in all other essential amino acids. The experiments ranged from 2 to 4 weeks in duration. The chick weight gains are shown in figure 2. In all the experiments the chick growth from the

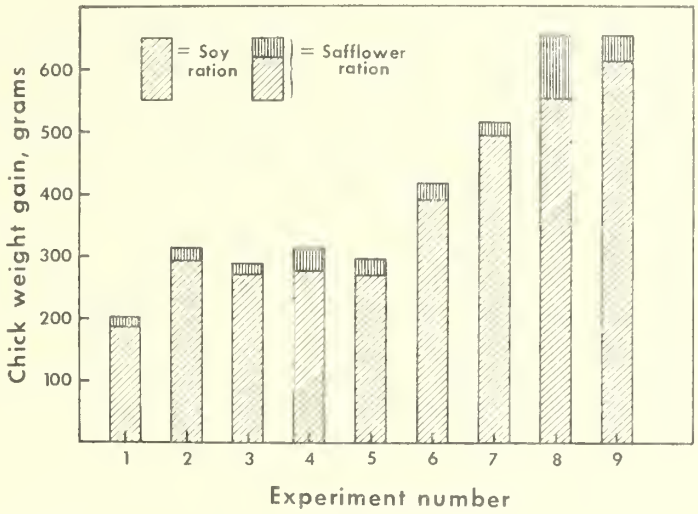

Figure 2. Chick growth on safflower and soy rations.

safflower rations was superior to that from the soy rations. Over the 9 experiments the chick-weight gain averaged 8.8 percent higher on the safflower rations. Figure 3 shows the feed efficiency for

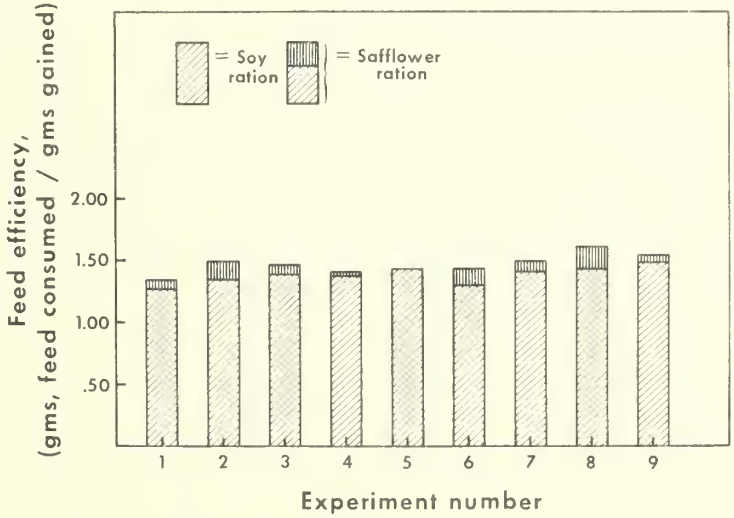

Figure 3. Feed efficiency on safflower and soy rations.

these 9 experiments. It averages 5.7 percent poorer for the safflower rations, demonstrating the relatively low metabolizable energy of the safflower meal. However, in experiments 5 and 9 the metabolizable energy of the safflower and soy rations were made equal and there was no significant difference in feed efficiency. Yet the safflower rations still seemed to produce better growth.

At the present high cost of lysine, it would not be economically feasible to add the amount of lysine that is added to these safflower rations. The most likely practical approach would be to use safflower meal to supply part of the protein source in broiler rations which are rich in lysine. We have conducted experiments along this line and the results do indicate that this is a feasible approach. However, the amount of safflower meal that could be put into the ration would depend primarily on the cost of the safflower meal and the cost of those feed ingredients which are rich in lysine.

In closing I would like to emphasize two points: (1) Adequately supplemented safflower meal promotes excellent chick growth. (2) With a favorable price break on high-lysine feed ingredients, safflower meal can be used to supply part of the protein source for commercial broiler rations.

DETERMINATION OF INTRINSIC VALUES OF FEED INGREDIENTS[1]

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Parametric linear programing is an ideal tool for feed formulation. Feed ingredients are selected according to price and nutritional content. Then intrinsic values can be determined by evaluating each one in relation to competing ingredients. The prices of competitors are fixed while the price of the test ingredient is varied from zero to a level sufficiently high to force it out of the ration. Parametric linear programing determines a series of points on an evaluation scale relating the quantity of a test ingredient to its cost in a given ration. At each point, the least-cost formulation is given in detail.

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[1]The work discussed here is an outgrowth of a cooperative research program between Economic Research Service and Agricultural Research Service, U.S. Department of Agriculture. G. O. Kohler, Chief of the Field Crops Laboratory of the Western Utilization Research and Development Division, ARS, played an important role in the research. Appreciation is expressed to Kenneth H. Maddy, Manager, New Project Development, The Monsanto Company, for technical coefficients and computer facilities.

For this paper dehydrated alfalfa meal (commonly shortened to "dehy") is used as an example. Safflower meal also lends itself to this type of analysis. It contributes several nutrients to a feed formulation. As soon as technical coefficients become available, parametric linear programing tests will be conducted on safflower meal.

Linear programing. Parametric linear programing is an extension of linear programing. The first application of linear programing in essentially its present form appears to have been made by George B. Dantzig in 1947. However, Dantzig did not publish his work until 1951 (1). In the same volume that carried Dantzig's work, there appeared an article by Hildreth and Riter making an application to an agricultural problem. Later in that same year F. V. Waugh of the U.S. Department of Agriculture made the first application to a cost minimization problem in agriculture--that of selecting a minimum cost feed (3). Since 1951 scores of articles on the technique itself and hundreds of reports of research employing the method have appeared. In a little over a decade the technique has revolutionized the feed industry.

Linear programing is similar in purpose to comparative budgeting--introduced almost a century ago. In comparative budgeting of ration-planning problems, we start with a set of requirements which are, to some degree, fixed. An example would be metabolizable energy, amino acids, vitamins, and minerals. Along with requirements we set limitations, such as maximum fiber and animal fat. After determining ration requirements and limitations, we start combining ingredients to meet them, until a combination is found that is not out of line in cost. Of course, what is out of line depends upon judgment and may well be a function of time available to work out additional combinations. In any event, it is possible to consider only a few requirements and a limited number of ingredients with this technique.

Now let us define linear programing. It is a technique for obtaining a unique value-weighted solution to a set of simultaneous linear equations in which the number of unknowns may exceed the number of equations and in which no variate has a negative value (3). This definition from F. V. Waugh makes linear programing sound much more sophisticated than comparative budgeting. This is probably because we seldom think of comparative budgeting or ration planning in terms of the underlying mathematical relationships.

The critical part of linear programing is matrix construction. It must meet the logic called for by the problem. Coefficients must be logical and have application to the problem. The mechanics of problem solving can never correct erroneous input data.

A least-cost linear programing matrix can be divided into three major areas for discussion: ration requirements and restrictions, ingredient analysis, and objective function. Ration requirements and restrictions set the standards a formulation must meet. They may be in the form of minimum, maximum, or equality statements. Energy and protein are examples of minimum requirements, fiber and animal fat of maximum requirements, while salt and weight show equality requirements. Since ingredients are necessary to meet ration requirements, each must be completely analyzed in relationship to the requirements. If this is not done, some of the standards are transgressed and the livestock will suffer. To achieve optimum results, coefficients for both ration requirements and ingredient analysis must be accurate to the best of our ability. The objective function is the factor that correlates the two sides of the problem (requirements and suppliers). It is that portion of the matrix that provides the weighting factor that enables all ration requirements to be met at the lowest possible cost. In least-cost formulation the objective function is derived from ingredient prices. Pricing for the objective function can reflect many circumstances. They can be current for a specific time and place, or they can reflect averages over a period of years. A combination may reflect the logic of the problem under consideration.

Linear programing does have limitations. First, most relationships deviate from linearity. Ingredients tend to interact to some degree, and livestock utilizes varying amounts of ingredients. It should be noted, however, that in most cases an assuming linearity is safer than assuming some other mathematical function. Second, one must assign specific values to each coefficient. In most cases, especially ingredient analysis and prices, they vary significantly. Therefore, one must remain conservative in making assignments. Third, while linear programing gives the least-cost ration on a given set of assumptions, it may not return as high a profit as some other formulation. This may be due to ingredient availability, level of inventories, plant layout, or other problems associated with frequent formulation changes. It should be noted, however, that most of these problems can be minimized by building proper restrictions into the matrix. As an example, if milo is in short supply, its use could be restricted to say 10 percent of a broiler ration.

Regardless of its limitations, linear programing is superior to most other analytical tools in solving feed-mix problems. Where comparative budgeting makes attempts at finding least-cost solutions, linear programing reaches the objective without fail. It should also be noted that comparative budgeting has the same limitations as linear programing without the advantages.

Once the matrix is constructed, solution is routine. Linear programing problems can be solved by hand, with a desk calculator, or with an electronic computer. The complexity of the problem dictates the medium used. The complexity of most problems, however, requires the computer.

The computer's greatest contributions are speed and accuracy. Present systems can make up to one million calculations per second, while some under consideration will handle a billion. While operating at these fantastic speeds, the computer is able to maintain complete accuracy. This is accomplished by a system of internal checks and balances. In addition to speed and accuracy, the computer is able to retain results of calculations and use them in later processes. This ability is often referred to as memory capacity.

In order to solve a problem on a computer, three items are required: hardware, software, and data. The hardware consists of the actual computer components. The software is the program that instructs the computer in solving specific problems. The data is information that has been systematically recorded and is needed to reach a problem solution. In linear programing, the mathematical matrix is composed of data. Solving a computer problem is much like driving an automobile. The hardware is like the automobile itself, the driver the software, and the fuel the data. All three are necessary for successful operation.

Parametric linear programing. Parametric linear programing is a further development of linear programing. It adds a degree of flexibility to an otherwise rigid structure. Its use enables one to parameterize (to analyze at different levels) at least one coefficient. The coefficient may be either a ration requirement, ingredient component, or price. In least-cost feed analyses price is usually chosen as the flexible item. The researcher chooses that ingredient he wants to study and then lets the price range through a broad spectrum to determine effects of change.

To parameterize an ingredient, the researcher must specify the price ranges and the increments of increase or decrease in price the computer is to consider. These increments may be very small, often less than one cent a ton in feed research. The computer will reach an optimum least-cost solution at the first price given. It then examines the solution at each increment of price change to see if a new formulation would lower cost. At each point where ration cost could be reduced, a new solution is given. As an example, if one is reducing the cost of the ingredient, each new solution will result in greater use of the ingredient at reduced ingredient price. With this procedure a series of points on a value plane can be determined that evaluates the ingredient at each level of use in the ration.

Intrinsic values of dehydrated alfalfa meal. Dehydrated alfalfa meal ("dehy"), like many other feedstuffs, contributes a complexity of nutrients, vitamins and minerals to a feed formula. Many have been identified and quantified; some have not. The most recognized contributions are amino acids, xanthophyll, vitamins A, K, and E, and the minerals calcium and phosphorus. Growth factors, though valuable, have not been individually identified nor quantified. Dehy, then, is a multifactor rather than a monofactor supplier. In contrast, some feed ingredients, such as synthetic vitamin A, are monofactor contributors.

A multiple-factor supplier is much more difficult to evaluate than a monofactor contributor. If all ingredients supplied only one item each and no detrimental factors, feed formulation would be simple. That ingredient supplying a specific requirement at the least cost per unit would always be selected in a ration. All other competitive ingredients would be evaluated in relationship to it. Also, if a multifactor ingredient supplied nutrients, vitamins, and minerals in the exact proportions called for by a ration, formulation would be simplified. Most ingredients, however, tend to be strong in some requirements and weak in others. Alfalfa meal is not an exception. Probably its greatest weakness is energy content. The energy-to-weight ratio in alfalfa meal is much less than is required in most rations.

Feed rations can be considered users of nutrients, vitamins, and minerals while ingredients are suppliers. The purpose of formulation is to combine ingredients in such a manner that ration requirements are met at the lowest possible cost. Ingredients then are competitors in meeting ration requirements. Because of their multifactor composition this competition becomes complex. They are competing on a multitude of items and not just one. Therefore, substitution of ingredients in a ration is multiphasic. As an example, in one combination of prices, "dehy" may be competing with soybean meal as a source of tryptophan, while in another combination it may be metabolizable energy. While competing with soybean meal on these items it will be competing with various other ingredients on the same factors plus a multitude of others. Without the computer, it would be impossible to keep track of this complexity.

We are presently evaluating "dehy" on a matrix developed by the Monsanto Chemical Company. The first computer runs were also made at their research facility at St. Louis, Mo. The matrix has over 75 ration requirements and considers up to 100 ingredients. The computers could easily handle much larger matrices, but this matrix was large enough for present feed formulation technology. In fact, only about 35 ration requirements and 30 ingredients were actually included in the tests. At the time of run, Monsanto nutritionists felt the 30 ingredients were the only

feedstuffs in sufficient supply for consideration. The 35 requirements were considered adequate for the rations included in the tests. Seven protein levels of "dehy" were tested: 13, 15, 17, 20, 22, 25, and 28 percent. Prices used for other ingredients were those at Kansas City in December 1966. Tests were made on broiler, finisher, and layer rations. On each of these, two levels of xanthophyll were tested. On the broiler-finisher ration the levels were 12 and 30 mg./kg., while on the layer ration the levels were 12 and 24 mg./kg. Therefore two runs were made for each ration. Each run produced a value curve for each protein level of dehy for a total of 28 curves. The price of each level of dehy was allowed to vary from $1,000 per ton to $0.00. Dehys of different protein levels were not tested against each other. Dehy of a given level of protein was tested against all other ingredients in the matrix with the exception of other alfalfa meals. Some results will now be presented.

The protein level of alfalfa meal (dehy) also reflects levels of other factors. A 20-percent protein meal, for example, has a higher percentage of vitamin A and xanthophyll as well as amino acids than a 17-percent meal. For this reason, a high-protein dehy will substitute for more ration requirements than one with low protein. Figure 1 includes the value curve for 28 percent dehy. Its value in this broiler-finisher ration (12 mg./kg. xanthophyll) varied inversely to amount used. Dehy appears first in the ration when the price came down to $162 a ton. At this price the ration included 0.33 percent dehy. At $144 the amount increased to 0.5 percent, and then to 1.5 percent at $130 per ton. The computer then called for a drastic price reduction before any additional meal could be used. It was necessary for the price to drop to $55 a ton, at which point 5.5 percent dehy was included. Below $55 a ton, small price decreases greatly increased the use of dehy. As the price dropped from $54 a ton to $47, the amount used climbed to almost 30 percent of the ration. The maximum dehy used at zero cost was about one-third of the ration. Greater use would have required a negative cost. It appears that dehy can compete with other feed ingredients at low levels of use. Whether or not the price that would be received at the higher levels of use would cover costs has not been determined.

At each point on the value curve the computer gives a complete ration formulation. In addition to the formulation it gives shadow prices (the amount the ration cost would increase with use of 1 unit of an ingredient not included in the solution) for the ingredients not used, and the opportunity cost (the amount the ration cost would increase or decrease with a change of 1 unit in ration requirement or restriction) for requirements in scarce supply. Examination of formulations, shadow prices, and opportunity costs usually reveals the significance of each point. At

point A (figure 1) tryptophan of dehy is substituted for tryptophan from some other source. At point B dehy vitamin A is substituted for synthetic vitamin A. At point C the substitution was dehy xanthophyll for corn gluten meal xanthophyll. Other points were determined and are shown on figure 1. The xanthophyll point seems to be most significant. At this point 28 percent dehy was valued at $130 a ton and made up 1.5 percent of the ration. At point D the value dropped to $55 a ton which would probably be below the cost of production for this level of meal. The greatest values of dehy in broiler-finisher rations were xanthophyll, vitamin A, and tryptophan.

Comparisons between value curves are perhaps even more interesting than analysis of individual curves. Figure 1 also illustrates the value curves for other protein levels of dehy--17 and 13 percent chosen for ease of presentation. If all seven protein levels were given on the same chart, the curves would be very messy. Since the curves are discontinuous, we have steplike functions. In substitutions for ingredient factors, the curves actually crossed each other in some cases. The most interesting items in curves comparing different protein levels are the points of substitution. As an example, point C on each of the curves is where xanthophyll in dehy substitutes for xanthophyll in corn gluten meal. For 28 percent dehy, it is 1.5 percent of the ration at a cost of $130 a ton; for 17 percent dehy, it is 4.1 percent of the ration at $50 a ton; for 13 percent dehy, 10.9 percent of the

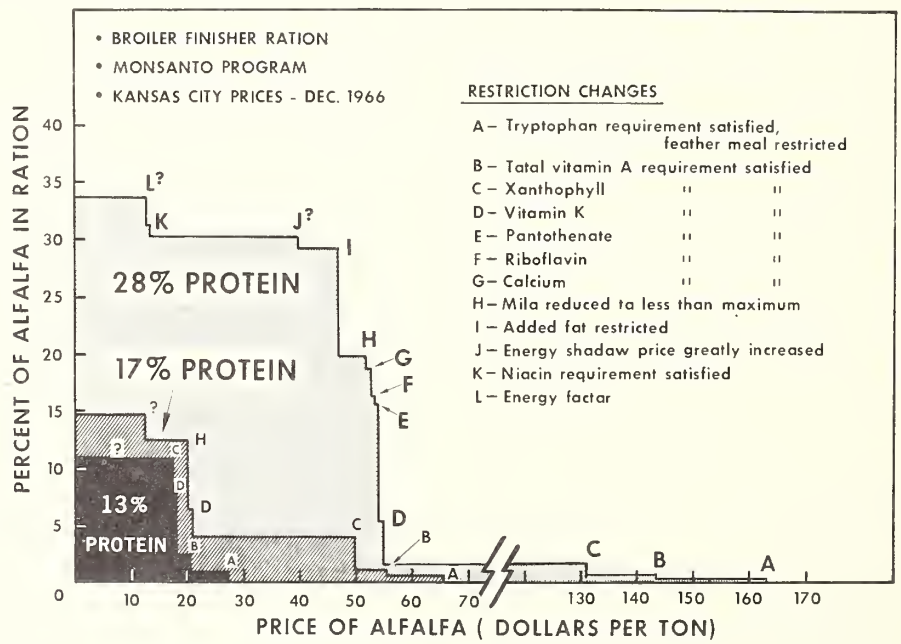

Figure 1.--Percent of dehydrated alfalfa in ration according to quality and price.

ration at $17 a ton. Further formulation analysis showed, with only minor exceptions, that at each point of factor substitution for each protein level, total cost of ration was identical. As an example, at point C, the xanthophyll substitution point, cost of ration in six of the seven protein levels was exactly $74.87. In this case, a feed formulator could be indifferent in mixing 1.5 percent of the 28 percent meal at a price of $130 a ton, 4.1 percent of the 17 percent meal at $50 a ton, or 10.9 percent of the 13 percent meal at $17 a ton. If this situation always holds true, parametric linear programing could be used to determine the break-even point between prices and quantities used for different levels of dehy. A small amount of a very high-protein dehy at a high price is no more costly to the formulator than a large quantity of low-protein dehy at a low price.

A second comparison showing value curves of 25 percent protein dehy in broiler-finisher and layer rations is shown in figure 2. Alfalfa meal had a higher value in layer rations at

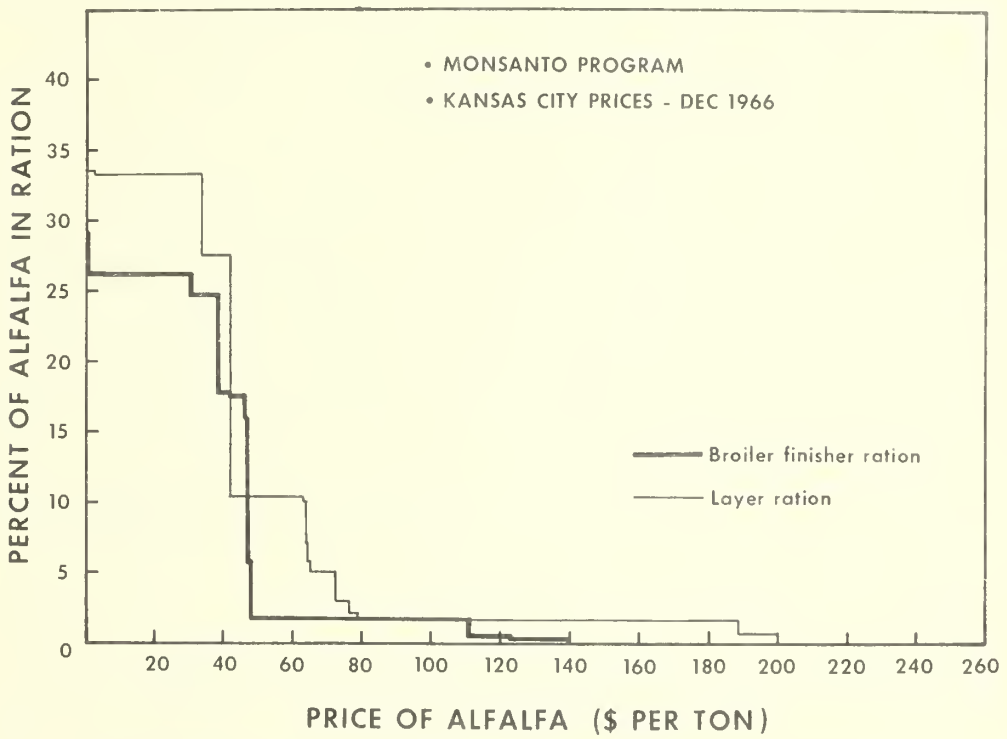

Figure 2.--Percent of dehydrated alfalfa in ration according to ration and price.

almost all comparative points of substitution than in the broiler rations. In the layer ration, the price started at $200 per ton of meal with 0.8 percent dehy in the ration. For the broiler-finisher ration the price started at $140 per ton with 0.4 percent in the ration. At zero cost for dehy, the layer ration included 33.6 percent dehy, and the broiler-finisher ration 29.4 percent.

This chart illustrates that intrinsic values of alfalfa meal are not absolute but vary according to ration requirements. They also vary according to competitive ingredients considered, locality of formulation, season, and price variations of competitive ingredients.

Figure 3 illustrates the effect of changing ration requirements. In this example, the requirements for xanthophyll in the layer ration were 12 and 24 mg./kg. Most of the curves were convergent. However, there was a significant difference at the point of xanthophyll substitution. The point for the 12 mg./kg. occurred at $189 per ton of dehy, making up 1.7 percent of the ration, whereas in the 24 mg./kg. requirement situation substitution occurred at $184 per ton of dehy, making up 4.2 percent of the ration. While the difference in price was small the difference in dehy used was large.

We have shown that parametric linear programing is an excellent device for determining intrinsic values of feed ingredients. It can be used to develop value curves for the entire range of prices and quantities used. At each solution point (point of substitution) a complete formula is given, and shadow prices are established for ingredients that do not come into the solution along with opportunity costs for ration requirements. A great many comparative analyses can be made, such as differences between product quantities, ration requirements, geographical areas, seasons of the year, ingredient analyses, and almost anything else that conforms to a few basic specifications. This type of analysis can also be used for items other than feed ingredient. Where it is used, however, all factors must be quantified and values determined primarily by intrinsic rather than extrinsic factors (package, contractual arrangements, etc.).

In addition to providing useful information to feed formulators, parametric linear programing can have tremendous value for the scientist. It can help him make decisions on the direction of research. He can evaluate alternative projects. Examples of questions that can be answered are: Does separation of alfalfa into fractions of different protein content justify cost? How do changes in xanthophyll requirement affect value of dehy? By how much can the value of dehy be increased by increasing metabolizable energy? Which dehy fractions should be fed to which class of livestock? How does dehy compete with substitutes on the West Coast vs. the East Coast? Which ration requirements are limiting factors and upon which should research be expended?

Similar questions can be answered for other feed products such as safflower meal and castor bean meal. At what prices and in what amounts can safflower meal serve as a source of protein

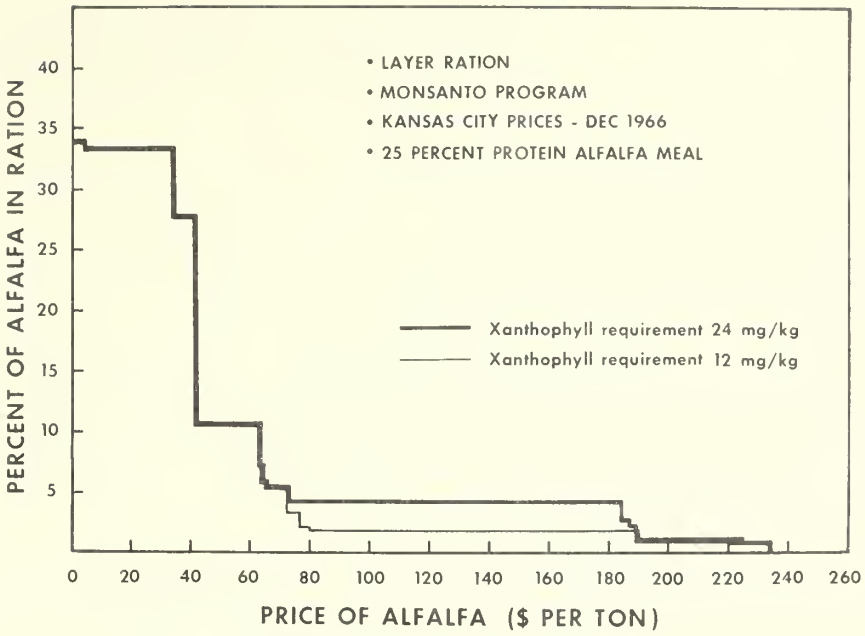

Figure 3.--Percent of dehydrated alfalfa in ration according to xanthophyll requirement and price.

in animal rations? To what degree should decortication of safflower be carried to give the most economical and useful protein supplement for food and feed? Can lysine supplementation increase the amount of safflower meal which can be economically utilized in animal rations? An example for castor would be: How much degradation of amino acids is economically allowable during detoxification and deallergenization of castor meal? Alternative analyses are limited only by the imagination of the researcher, the time he has for analyses, and money available for computer time.

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SAFFLOWER PROTEIN PRODUCTS FOR FOOD USE

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In marketing safflower meal products for use in feeds, the primary considerations are cost and nutritional value. In developing products for use in the poorly fed areas of the world, the emphasis is on nutritional needs.

I will talk about a third aspect--the use of safflower meal protein products in domestic foods. For this use, emphasis is on the functional properties of the protein, not its nutritional advantages. In the United States, vegetable proteins are used primarily where they impart some desirable quality to the final product, or where they assist in processing.

I should say at the outset that safflower protein is not used in this way. The discussion then must be limited to pointing out the potential of safflower protein in foods. The present leader in the field is soybeans. Safflower will have to try harder, just to become No. 2.

The present uses of soy protein are a direct result of extensive research and development over many years. There is no reason why we cannot use these developments to promote use of safflower products. It is of direct interest then to consider first some of the developments in food uses of soy proteins.

The present markets for soy-protein foods products are: (1) Flour, about 300 million pounds at 13 cents per pound; (2) concentrate, 15 to 18 million pounds at 18 to 28 cents per pound; and (3) isolate, 10 to 12 million pounds at 35 to 38 cents per pound. It is significant that these large uses of soy protein food products have developed only as the result of intensive research on the part of government and private organizations.

Soy flour ranges from 45 to 50 percent protein and is available with varying fat content and protein dispersibility. A major factor in the use of soy flours is cost reduction, for the protein can substitute for some of the milk used in many formulated products, and the oil content can be used to reduce the shortening requirements. Equally important is the fact that use of soy flours often results in product improvement.

Soy flour can substitute for some of the milk in bakery products, where the soy protein is replacing casein. The oil in high-fat soy flour can also reduce the need for shortening. Soy

flours improve the texture, crust, and keeping qualities of baked goods, aid in retention of moisture and fat in prepared meats, and serve to adjust the viscosity of products such as gravies and puddings. Soy flours are used in breads, various other bakery products, breakfast cereals, soups, snack items, baby foods, prepared cake mixes, prepared meats, candies, gravies, and puddings. In all of these products, the level of use is restricted principally by undesirable flavor.

Soy protein concentrate contains about 70 percent protein, and it is made by extraction of solubles from soy flour by alcohol or dilute acid. The concentrate has an advantage over the flour in that the removal of flavor components allows much higher levels in the final product. Pancakes with 37 percent soy concentrate have a light, fluffy texture, and a flavor like corn. In ground meats, 1 pound of concentrate can replace 3 pounds of meat, since the dry concentrate can absorb two or three weights of water. The protein content of the product is increased over that of all-meat product. The concentrate is a relatively new product, but it has been found to be particularly useful in sausage emulsions, as a thickening agent, and as a conditioner in meat patties to give cohesiveness without stickiness.

Isolated protein is made by precipitation at the isoelectric point, and can be made with a wide range of functional properties. With proper modification it is a superior whipping agent and, among other uses, finds application in the foam-mat drying process, which was developed here. It is used in frozen desserts, in making improved dehydrated meats, as an adhesive in chicken or turkey rolls, as a spread on boned hams, and as an aid in processing of many meat products.

In addition to its uses in conventional products, a wide variety of new products are now available from "textured" isolate or flour. Several ways have been found to make extruded fibers, which then can be formed into meatlike products resembling ham, pork, beef, chicken, meat loaf, etc., or into completely new foods with a variety of flavors.

These diverse uses of soy protein products are primarily due to the functional properties, not to the nutritional aspects of the protein. The important considerations are cost reduction, processing improvement, or product improvement. The question now arises, "What are the prospects for safflower?"

There are no present uses of safflower protein in U.S. foods. Safflower meals contain too much fiber to be useful in foods. In addition, there are bitter flavor components, which persist in foods cooked with untreated meals. We have recently confirmed earlier

reports of cathartic activity in the meal. In 1961 V. M. Chavan, Central Oilseeds Committee, Hyderabad, India, reported ancient Sanskrit and Greek references to the use of safflower seed as a laxative. I noticed that Professor Knowles also listed this as one of the virtues ascribed to safflower by some people in the Middle East.

We should remember, however, that similar problems are found in meals from other oilseeds, and that processing methods have been developed for making food products from soy and cottonseed. Indeed, we have found that flour, concentrate, and isolate can be made from safflower. Table 1 shows the results of grinding and sieving commercial 42 percent protein meal in a laboratory flour mill (Quadramat Senior). Approximately half of the hull fraction can be removed, with only a small loss of protein. The fiber content is still somewhat above the recommended maximum for food protein supplements but may not be too high for some uses where only a small proportion is used in the final product.

Table 1.--Hull removal from commercial meal by flour milling

Product	Composition and yield, percent dry basis			
	Protein	Hull[1]	Other	Yield
Commercial meal	50	27	23	100
Flour	55	17	28	79
Bran	15	76	9	21

[1]Calculated: crude fiber x 2.

Table 2 shows some of the low-fiber products which we have made by a laboratory process from brown-stripe seed. Most of the hull was removed by screening and aspirating the cracked seed before removal of oil. Half of the hull remaining in the meal was removed by milling to produce a flour with an acceptably low fiber content. The edible concentrate was made by alcohol extraction of the flour. This step removes the bitter flavor and also removes the laxative components.

Table 2.--Low-fiber products from brown-stripe seed

Product	Composition, percent dry basis				
	Protein	Hull[1]	Fat	Ash	Other
Meal	64	9	1	8	18
Flour	67	6	1	8	17
Concentrate	81	7	1	9	2

[1]Calculated: crude fiber x 2.

Safflower protein solubility is quite similar to that of soy protein, and a bland isolate can be recovered by acid precipitation. This also permits the preparation of fibers for use in

textured-protein products. A patent (U.S. Patent 3,175,909, L. F. Elmquist, assigned to General Mills, Inc.) has been issued on the preparation of spun fibers from safflower meal.

In preliminary tests of edible safflower concentrate in bread and in meatlike patties, we have found that results are similar to those obtained with soy concentrate. I feel that the conclusion may then be drawn that with further research on practical processing methods, protein products similar to those obtained from soy can be obtained from safflower. In view of the fact that markets now exist for these products, and that these markets are expanding, it seems that such efforts would be very much worthwhile.

AMINO ACID COMPOSITION OF SAFFLOWER MEAL-- A FAST HYDROLYSIS PROCEDURE

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To you who have been listening to the papers presented thus far, it is obvious that safflower is definitely in the "have not" category so far as lysine is concerned. Mr. Kuzmicky has presented evidence that safflower meal by itself is clearly deficient in lysine for poultry, because improved growth can be obtained either by lysine supplementation or by addition of lysine-rich soy meal to chick rations. It is apparent that safflower meal is also deficient in lysine for human beings. This lack is unimportant in this country because we get plenty of lysine from other proteins. In the developing countries, however, the low lysine level would be undesirable if safflower meal were to become a prominent protein source.

The discovery of high-lysine corn has raised hope that for every low-lysine commodity higher-lysine varieties can be found. Most cereals, along with safflower, are notably deficient in lysine, and so considerable activity can be anticipated in this research area.

As Dr. Rubis indicated in his discussion of genetic studies, screening large numbers of samples in search of a high-lysine variety is an absolute necessity. We must think big and not be afraid to contemplate surveys of world collections involving

thousands of varieties. For survey studies, chemical methods must emphasize speed and ease of handling large numbers of samples rather than absolute methodological accuracy. What we are interested in are relatively large differences in lysine content (e.g. 20 percent or more above the average). Promising leads uncovered during the screening process can be reinvestigated later by more accurate but also more time-consuming methods.

With this consideration in mind, we looked at our conventional lysine analysis to see what steps could be simplified or eliminated. In our laboratory the steps ordinarily involved in oilseed protein analysis include crushing the seeds, extracting oil, grinding to make a uniform sample, weighing into an ampoule, adding acid, sealing under vacuum, heating 24 hours, opening ampoule, filtering the hydrolysate carefully, evaporating and drying the hydrolysis residue, dissolving it in buffer, and running an aliquot on the automatic amino acid analyzer. This is obviously not a speedy process nor is it well suited for mass production methods. The time-consuming hydrolysis step cannot be eliminated, because all lysine analyses call for measurement of the free amino acid. However, most of the time involved is from 5:00 p.m. to 8:30 a.m. the next morning. Thus, the long heating period is not a serious drawback as operator time is not involved.

It did seem possible to throw out the crushing, oil extraction, grinding, and vacuum sealing steps prior to hydrolysis and simplify the filtering and drying steps afterwards. That is, we could do this if we were willing to accept some loss of accuracy in favor of saving time. Evaluation of foods and feeds in regard to a particular amino acid is usually based on the ratio of the amino acid to the total amount of nitrogen present (e.g. grams of amino acid per 16 grams of nitrogen). Thus, quantitative recovery of hydrolysate is not necessary--the only requirement is that the relative recovery of amino acid and total nitrogen be the same. The principle is essentially the same as that used in isotope dilution methods; it does not matter how much you lose as long as you lose the same amount of all components and still have enough to measure. The simplified procedure seemed feasible because previous work here showed that during hydrolysis lysine is fully liberated in 24 hours and is completely stable throughout the procedure.

Bearing in mind what we needed and were prepared to accept, we devised a highly efficient hydrolysis method which we call "the survey method." For a single sample, approximately 2 grams of whole seed (undefatted, unground) are put in a glass vial. Acid is added, the Bakelite cap is screwed on the vial, the vial is placed in a rack with other vials, and the whole rack heated at 110° for 24 hours. Each rack holds 49 vials and an operator

can easily set up 98 per day. The next day the tubes are cooled and crudely filtered through paper into plastic vials. There is no washing of vial or funnel because we are not concerned about quantitative recovery. The samples are evaporated in a vacuum oven which has been painted inside with neoprene to cut down corrosion. When in operation we use a polyethylene sheet to protect the door and gasket. An infrared lamp on low heat prevents vapor condensation on the window. After 24 hours, when the samples are dry, they are removed, wetted with 2 ml. more of water and reevaporated to lower the HCl concentration to an acceptable level. The dried samples are capped and analyzed when convenient. Usually about 300 samples were processed each week. The equipment used in this procedure is inexpensive and durable.

Table 1.--Effect of hydrolysis methods on apparent lysine content of safflower[1]

Weight	Lysine	N	Ratio lysine to N	Lysine
g.	μmole/ml.	mg./ml.	μmoles/mg.	g./16 g. N
Conventional hydrolysis method--defatted meal				
0.040	0.194	0.158	1.23	2.87
.040	.206	.165	1.25	2.92
.100	.314	.251	1.25	2.92
Survey method--whole seeds				
2.0	.356	.279	1.28	2.98
2.0	.388	.292	1.33	3.11
2.0	.287	.235	1.22	2.86
2.0	.236	.188	1.26	2.94

[1]Commercial thick-hulled variety, 15.4 percent protein.

Table 1 shows a comparison of the results of the conventional and the survey hydrolysis methods on safflower, indicating satisfactory agreement between them. You will notice that although the actual levels of lysine and nitrogen vary markedly among the survey-hydrolyzed samples, the ratios and, consequently, the g./16 g. N value are the same for all. This shows that hydrolysis was complete in all cases and solution losses subsequent to hydrolysis are unimportant and bear out the fact that proportionate amounts of lysine and nitrogen were lost. Therefore, our assumption that there is no need for quantitative manipulation prior to actual determination of lysine and nitrogen on the final aliquot is justified.

Table 2 shows the results of the testing on grain samples. The survey method of hydrolysis for grains gives lysine values approximately 10 percent higher than the conventional method. To make sure there were no contaminants in the lysine peak on the

Table 2.--Effect of hydrolysis methods on apparent lysine content of grains

Grain and protein content	Grams lysine per 16 g. N	
	Conventional procedure	Survey procedure
Wheat (15.1 percent protein)	2.68	2.75
Do ----------	2.50	2.66
Do ----------	2.44	2.83
Do ----------	--	2.82
Barley (11.6 percent protein)	3.39	3.65
Do ----------	3.29	3.75
Do ----------	--	3.68
Do ----------	--	3.72
Red milo (10.4 percent protein)	2.11	2.32
Do ----------	2.07	2.30
Do ----------	--	2.34
White milo (10.3 percent protein)	1.99	2.13
Do ----------	1.95	2.18
Do ----------	--	2.16
Do ----------	--	2.20

analyzer, we ran survey-hydrolyzed samples of red milo and safflower using the physiological fluid system of the analyzer that gives better amino acid separations. The reason we obtained higher values in high-carbohydrate commodities such as grains by the survey procedure is probably due to the use of a low acid-to-sample ratio. As long as the survey method of hydrolysis gives consistent results, the slightly elevated ratio values would not interfere with selection of high-lysine samples.

In conclusion, we have developed an adequate hydrolysis method for screening the large numbers of samples required for genetic studies. The hydrolysis method, along with the methods to be described by our next speaker, were put to a practical test in surveying about 2,500 samples of safflower in Professor Knowles' world collection of safflower seeds. Results show some apparent differences in the lysine-nitrogen ratio; occasional higher-than-average values occur. We are currently in the midst of a statistical evaluation of all data and a thorough chemical analysis of some of the seemingly high lysine seeds. No increase has been discovered in a safflower variety that is as spectacular as that of high-lysine corn, but enough variation has been uncovered to make further investigation of the problem worthwhile.

APPLICATION OF AUTOMATED ANALYSIS TO ESTIMATIONS OF LYSINE AND TOTAL AMINO ACIDS IN SAFFLOWER SEED HYDROLYSATES

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In the preceding paper a rapid survey hydrolysis procedure was described. It enables an operator to process up to 300 samples per week. To avoid quantitative recoveries of products in several steps of the survey hydrolysis procedure, two separate analyses must be run on aliquots of the hydrolysate: first, lysine, and second, some other constituent of the hydrolysate that is a measure of the total protein in the seed, which undergoes the same losses as does lysine during the preparation of the hydrolysate. Total amino acid is the most easily determined constituent that meets the requirements for the second determination.

In view of the dual estimations required on the large number of samples, we sought an automated system that would make both estimations simultaneously on the same portion of hydrolysate. The AutoAnalyzer, made by Technicon Corp., has been used for the automatic estimation of lysine in fermentation broths by an enzymatic method and also for measuring total amino acid content of protein hydrolysates. We have adapted the AutoAnalyzer to the simultaneous, automated estimation of the lysine and total amino acid concentrations in safflower hydrolysates. The ratio of lysine to amino acid concentration in the hydrolysate serves as a measure of the relative quality of the seed protein with respect to lysine.

The enzymatic method for the estimation of lysine is based on the fact that the enzyme L-lysine decarboxylase specifically catalyzes the decarboxylation of L-lysine to form cadaverine and carbon dioxide. The reaction may be shown as:

$$\text{L-lysine} \xrightarrow[\text{decarboxylase}]{\text{L-lysine}} \text{cadaverine} + CO_2$$

The automated estimation of lysine in the hydrolysates is achieved by the continuous colorimetric determination of carbon dioxide liberated by the enzymatic decarboxylation of the L-lysine. Total amino acids in the hydrolysates are estimated by the usual colorimetric ninhydrin method as modified for use on the AutoAnalyzer.

Figure 1 shows a schematic flow diagram for the simultaneous automatic estimation of L-lysine and total amino acid in the hydrolysates. Samples for both determinations are pumped simultaneously from the same sample cup. The lysine sample is mixed with the buffered enzyme and the stream is segmented with CO_2-free

air. After thorough mixing the sample is incubated with enzyme at 37°C. The carbon dioxide liberated by the decarboxylation reaction enters the air phase and is separated from the liquid phase at the gas-liquid separator. The gas phase, containing the carbon dioxide, segments a weakly alkaline buffer containing a pH indicator. The carbon dioxide is absorbed by the buffer, causing a decrease in pH and consequently a decrease in the intensity of the color of the buffer. The intensity of color is continuously monitored by a colorimeter and the results are presented as a curve on a 2-pen strip-chart recorder tracing. The amount of decrease in color of the buffer is proportional to the concentration of lysine in the hydrolysate.

The amino acid sample is diluted with methyl cellosolve and is segmented with nitrogen. After mixing, ninhydrin reagent is added. After further mixing the solution is heated to 95°C. to develop the characteristic ninhydrin-amino acid blue color. The intensity of color is continuously monitored by a colorimeter and the results are presented as a curve on the recorder tracing. The amount of increase in blue color is proportional to the concentration of total amino acid in the hydrolysate.

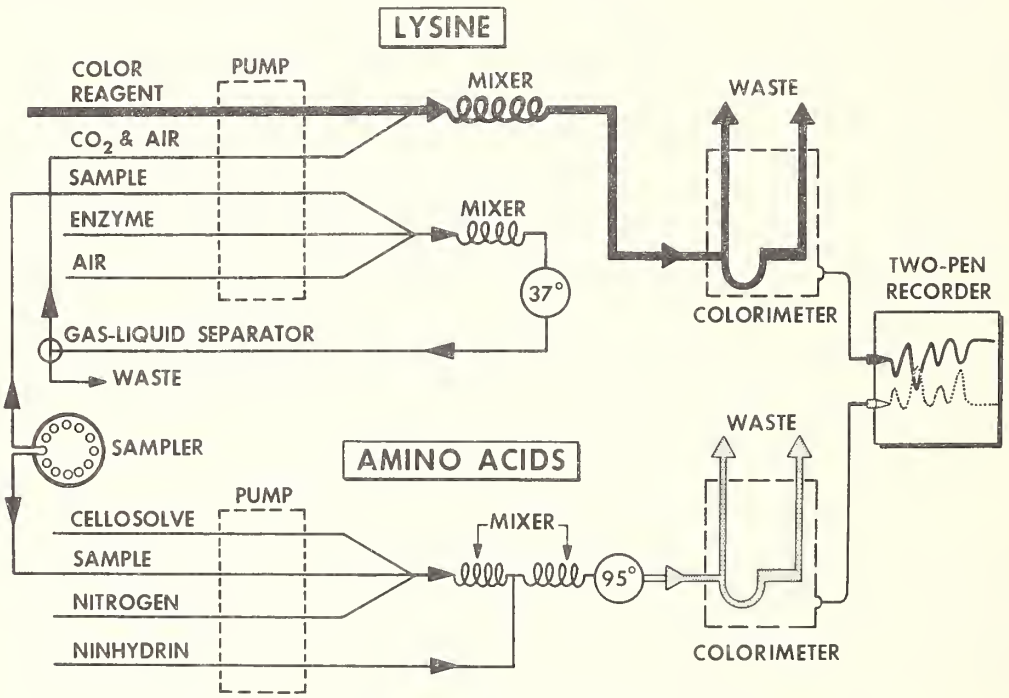

Figure 1. Flow diagram of analytical system.

In the present method the samples are run at the rate of 30 per hour. A typical recorder tracing is shown in figure 2. The pairs of peaks labeled A, B, C, and D represent calibration standards. The heights of these peaks permit the concentration of the hydrolysates represented by the other peaks to be calculated as

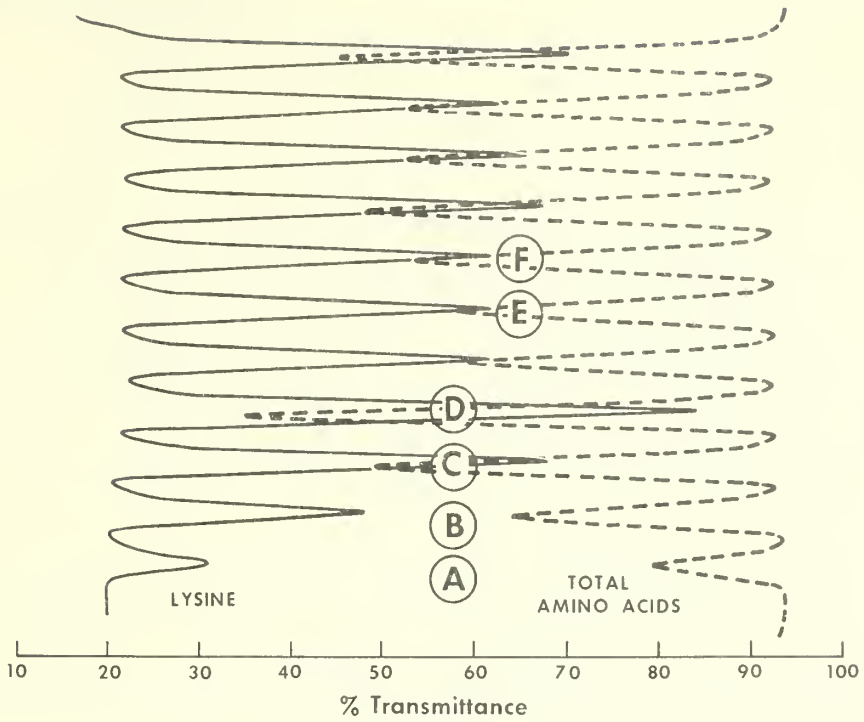

Figure 2. Typical recorder tracing.

micromoles of L-lysine per milliliter and micromoles of total amino acid per milliliter. Two pairs of peaks labeled E and F are of particular interest. They show that two hydrolysates had the same concentration of lysine but markedly different amino acid concentration.

Results. The precision of lysine results for the same hydrolysate run on 10 consecutive days is summarized:

	µmoles/ml.
Average	1.18
Maximum	1.21
Minimum	1.15
Standard deviation	.03
Number of determinations	10

To measure the accuracy of the lysine estimation, three hydrolysates were repeatedly analyzed by the enzymatic method and the results were compared with values obtained by ion exchange chromatography using an automatic amino acid analyzer. An ion exchange column of high resolving power (designed for physiological fluids) was used to avoid interferences by ornithine produced during hydrolysis. The results, in micromoles per milliliter, are shown as follows.

Enzymatic method µmoles/ml.	Ion exchange method µmoles/ml.
1.18	1.16
0.78	0.79
1.24	1.24

The results for lysine show adequate agreement by the two methods. The precision of amino acid results for the same hydrolysate run on 10 consecutive days is summarized below:

Total amino acids:	µmoles/ml.
Average	28.5
Maximum	29.0
Minimum	27.5
Standard deviation	0.57
Number of determinations	10

It is the purpose of this method to pinpoint those safflower varieties that may have an unusually high ratio of lysine to protein, or in this case, lysine to total amino acid. An easily calculated survey ratio that can be used to compare the relative quality of safflower protein with respect to lysine is

$$R = \frac{\text{µmoles lysine per ml. x 100}}{\text{µmoles total amino acid per ml.}} .$$

To show the precision for the "R" values obtainable by this method, including hydrolysis and estimation, 14 samples of the same lot of seed were hydrolyzed as a group by the survey hydrolysis procedure and were analyzed in duplicate on the same day, as shown below:

	R values
Average	4.63
Maximum	4.80
Minimum	4.45
Standard deviation	0.10

The automated methods described should permit the preliminary survey of large numbers of safflower seeds to identify those varieties that may have an unusually high ratio of lysine to total protein. Careful analysis by conventional methods should be performed on those varieties found most likely to have a lysine-rich protein.

The analytical services by Mrs. A. T. Noma and Mrs. B. A. Ricci are gratefully acknowledged.

LYSINE CONTENT OF SINGLE SAFFLOWER KERNELS

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As a part of this Laboratory's studies on the lysine content of safflower protein, it was considered useful to determine the least difference that can be expected in lysine content of protein in seeds of a variety grown under the same climatic and cultural conditions. It was also of interest to learn whether the protein in kernels from one region of the head has the same lysine content as in other regions.

These questions were answered by microanalysis of selected single safflower seed kernels for their lysine and nitrogen contents.

Experimental. Six heads of Gila (Row 808, 1966) and six heads of a cross of 56-15 x 57-67 (Row H_1, 1966), hereafter called "cross," were obtained through the courtesy of P. F. Knowles, University of California, Davis. Selected individual seeds were removed and dehulled by hand. The whole kernel was then extracted with hexane for 48 hours in a Soxhlet extractor. Each extracted kernel was vacuum dried and hydrolyzed 24 hours in 6N hydrochloric acid at 110°C. under nitrogen. After removal of the excess acid, the hydrolysates were dissolved in pH 2.2 citrate buffer. The lysine concentration of each hydrolysate was determined by the method of Spackman, Stein, and Moore, with an automated amino acid analyzer. The nitrogen concentration was determined by a microkjeldahl method.

Results and conclusion. Nine pairs of adjacent seeds were removed from one of the Gila heads at the positions indicated in figure 1. The lysine content of each of the kernels selected is shown. The average for all kernels is 2.97 g. lysine per 16 g. nitrogen and the standard deviation is 0.09.

Figure 2 shows results of a similar study on a cross head. The average for all kernels is 2.79 g. lysine per 16 g. nitrogen and the standard deviation is 0.10. One shriveled kernel was found near the center of this head. The protein in this kernel was 25 percent richer in lysine than the average for the protein in the other kernels in the head. Neither of the heads showed a tendency for the kernels in any region to be richer in lysine than kernels in other regions.

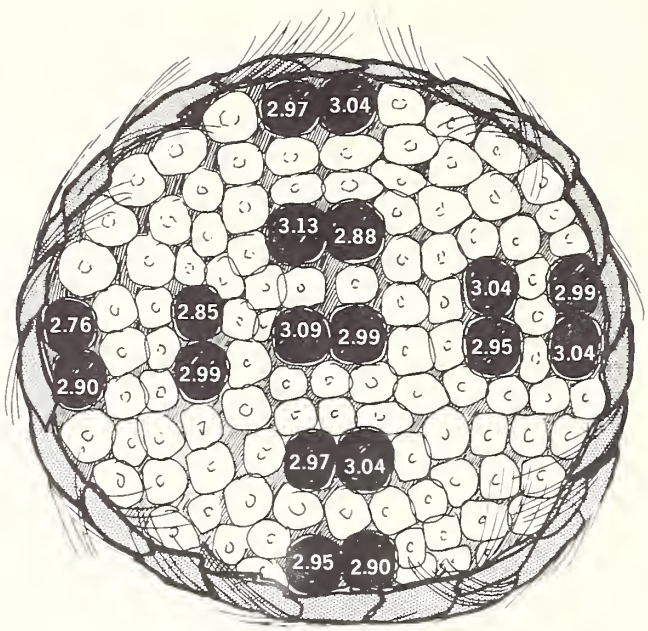

Figure 1. Lysine content of Gila kernels at selected locations (g. lysine per 16 g. nitrogen).

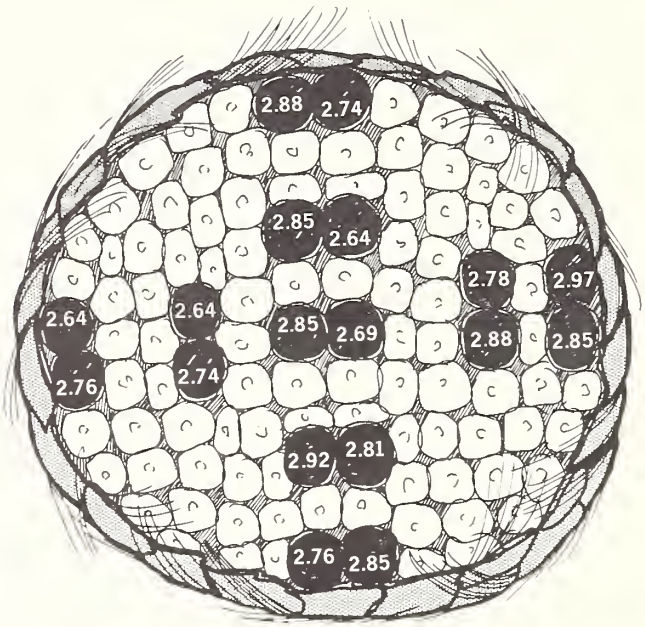

Figure 2. Lysine content of cross kernels at selected locations (g. lysine per 16 g. nitrogen).

A study was also made to determine the extent of variability of the lysine content of the kernel protein in heads of the same variety grown in the same row. For this study, the two center seeds

were removed from each of the five remaining heads of both varieties. The kernels from these seeds were then analyzed. The lysine contents of the center kernels of all six heads of both varieties are shown in figure 3. Because the results from the first and sixth

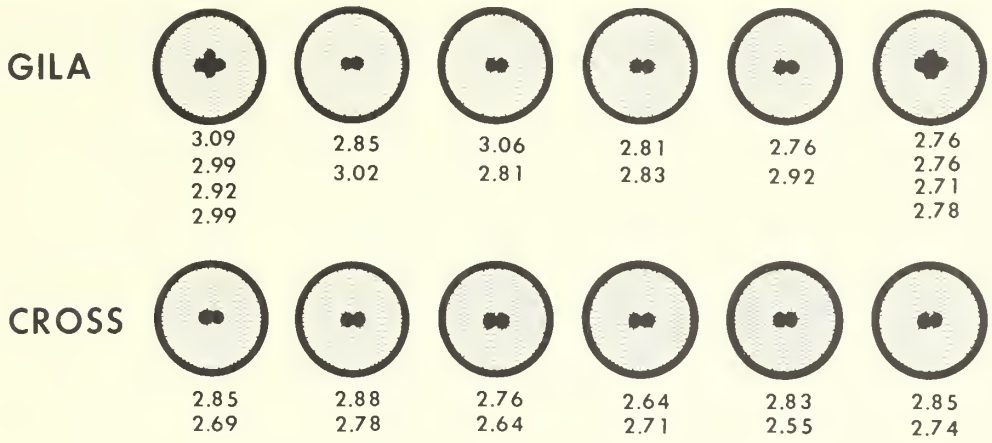

Figure 3. Lysine content of center kernels in different heads (g. lysine per 16 g. nitrogen).

heads of Gila showed considerable difference, two additional center kernels from each of these heads were selected and analyzed. A t-test on the results of the four center kernels from the two heads showed that these heads are significantly different at the 1 percent level. The heads of the cross variety appear to be essentially the same.

Summary. Analysis of single safflower kernels from the same head shows that protein in kernels in one region of the head is not significantly richer in lysine than is the protein in kernels from other regions. The lysine content of protein in safflower kernels from different heads grown in the same row may be significantly different at the 1 percent level.

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